

WL-TR-94-4014

**AD-A280 038**

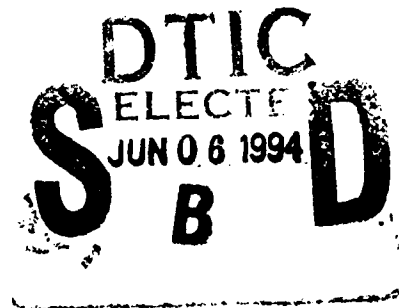


**THE MECHANICAL PROPERTY DATA BASE FROM AN  
AIR FORCE/INDUSTRY COOPERATIVE TEST PROGRAM ON ADVANCED  
ALUMINUM ALLOYS**

**MARY ANN PHILLIPS and STEVEN R. THOMPSON**  
Materials Engineering Branch  
Systems Support Division

December 1993

Final Report for Period July 1986 - May 1993



Approved for public release; distribution is unlimited.

DTIC QUALITY INSPECTED 2

Materials Directorate  
Wright Laboratory  
Air Force Materiel Command  
Wright-Patterson Air Force Base, Ohio 45433-7734

**94-16637**



94 6 3 082

## NOTICE


When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

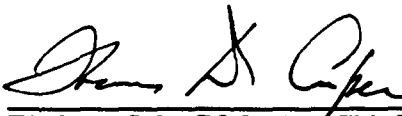
This report is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This Technical report has been reviewed and is approved for publication.

  
MARY ANN PHILLIPS, Project Engineer  
Engineering and Design Data  
Materials Engineering Branch

  
STEVEN R. THOMPSON, Project Engineer  
Engineering and Design Data  
Materials Engineering Branch

  
THEODORE J. REINHART, Chief  
Materials Engineering Branch  
Systems Support Division  
Materials Directorate

  
THOMAS D. COOPER, Chief  
Systems Support Division  
Materials Directorate  
Wright Laboratory

If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization, please notify WL/MLSE, WPAFB, OH 45433-7718 to help us maintain a current mailing list.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.					
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE December 1993		3. REPORT TYPE AND DATES COVERED Final 7/86 - 5/93	
4. TITLE AND SUBTITLE The Mechanical Property Data Base from an Air Force/Industry Cooperative Test Program on Advanced Aluminum Alloys.				5. FUNDING NUMBERS PE: 62102F PR: 2418 TA: 07 WU: 03	
6. AUTHOR(S) Mary Ann Phillips and Steven R. Thompson					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Materials Directorate Wright Laboratory Air Force Materiel Command Wright-Patterson Air Force Base OH 45433-7734				8. PERFORMING ORGANIZATION REPORT NUMBER  WL-TR-94-4014	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Materials Directorate Wright Laboratory Air Force Materiel Command Wright-Patterson Air Force Base OH 45433-7734				10. SPONSORING/MONITORING AGENCY REPORT NUMBER  WL-TR-94-4014	
11. SUPPLEMENTARY NOTES					
12a. DISTRIBUTION/AVAILABILITY STATEMENT  Approved for Public Release; distribution is unlimited.				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  This report contains a mechanical property data base on aluminum-lithium alloys 2091, 8090, IN905XL, AL905XL, and Weldalite 2095 and a data base on powder metallurgy alloys 7064 and CW67. Basic mechanical property data consist of tension, compression, shear, bearing and fracture toughness properties. Fatigue data were generated from both smooth and notched specimens. Constant amplitude fatigue crack growth rate data and spectrum fatigue test data were generated. Other tests performed on a select number of alloys were ballistic, hardness and conductivity.					
14. SUBJECT TERMS Weldalite <sup>TM</sup> Aluminum-Lithium 2091 8090 AL905XL IN905XL Tension Compression Shear Fatigue 2095 Spectrum Crack Growth				15. NUMBER OF PAGES 577	
17. SECURITY CLASSIFICATION OF REPORT Unclassified				16. PRICE CODE	
18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified		19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified		20. LIMITATION OF ABSTRACT UL	

## TABLE OF CONTENTS

<u>SECTION</u>	<u>PAGE</u>
1 INTRODUCTION	1
2 MATERIALS AND TESTS	3
3 PRESENTATION	4
4 RESULTS AND DISCUSSION	5
5 CONCLUSIONS	6
 <u>APPENDICES</u>	
APPENDIX A PECHINEY'S 2091 PLATE	7
APPENDIX B PECHINEY'S 2091 SHEET	61
APPENDIX C PECHINEY'S 2091 FORGING	113
APPENDIX D PECHINEY'S 8090 T-EXTRUSION	130
APPENDIX E ALCAN'S 8090 EXTRUSION	139
APPENDIX F ALCAN'S 8090 PLATE	181
APPENDIX G INCO'S IN905XL FORGING	203
APPENDIX H INCO'S AL905XL FORGING	248
APPENDIX I REYNOLD'S 2095 PLATE	271
APPENDIX J ALCOA'S 2091 0.063 INCH SHEET	308
APPENDIX K ALCOA'S 2091 0.144 INCH SHEET	338
APPENDIX L ALCOA'S 2091 PLATE	392
APPENDIX M ALCOA'S 8090 T-EXTRUSION & L-EXTRUSION	405
APPENDIX N KAISER'S 7064 EXTRUSION	426

<b>Accession For</b>	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification _____	
By _____	
Distribution/ _____	
<b>Availability Codes</b>	
Dist	Avail and/or Special
A-1	A-1

**TABLE OF CONTENTS Continued**

<b><u>APPENDICES</u></b>		<b><u>PAGE</u></b>
<b>APPENDIX O</b>	<b>KAISER'S 7064 FORGING</b>	<b>443</b>
<b>APPENDIX P</b>	<b>ALCOA'S CW67 SHEET</b>	<b>467</b>
<b>APPENDIX Q</b>	<b>ALCOA'S CW67 PLATE</b>	<b>484</b>
<b>APPENDIX R</b>	<b>ALCOA'S CW67 EXTRUSION</b>	<b>489</b>
<b>APPENDIX S</b>	<b>ALCOA'S CW67 FORGING</b>	<b>519</b>

## LIST OF FIGURES

<b>FIGURE</b>		<b>PAGE</b>
A1	R-Curve Results for 2091-T351 0.42" Plate (longitudinal)	19
A2	R-Curve Results for 2091 T351 0.42" Plate (transverse)	19
A3	R-Curve Results for 2091 -T351 0.42" Plate (longitudinal)	20
A4	R-Curve Results for 2091-T351 0.42" Plate (transverse)	20
A5	Fatigue Results for 2091-T351 0.42" Plate R=0.1, Kt=1.0	25
A6	Crack Length Versus Flights for 2091-T351 Plate FALSTAFF Loading, Max Stress=20 KSI	26
A7	Crack Length Versus Flights for 2091-T351 Plate FALSTAFF Loading, Max Stress = 30 KSI	26
A8	FALSTAFF Spectrum Results for 2091-T351 Plate Reduced in Terms of Growth Rate and Maximum Spectrum Stress Intensity	27
A9	Crack Length Versus Flights for 2091-T351 Plate Mini-TWIST Loading , Max Stress = 17 KSI	28
A10	Crack Length Versus Flights for 2091-T351 Plate Mini-TWIST Loading, Max Stress = 26 KSI	28
A10A	Fatigue Crack Growth Rate Data for 2091-T351 0.42" Plate L-T Orientation, General Dynamics, CA	29
A10B	Fatigue Crack Growth Rate Data for 2091-T351 0.42" Plate T-L Orientation, General Dynamic, CA	30
A11	Fatigue Results for 2091-T8X Plate R=0.1, Kt=1.0, Northrop	49
A12	Fatigue Results for 2091-T8X Plate R=0.1, Kt=3.0, Northrop	51
A13	Fatigue Crack Growth Rate Data for Pechiney 2091-T8X Plate L-T Orientation, Northrop	52
A14	Fatigue Crack Growth Rate Data for Pechiney 2091-T8X Plate T-L Orientation, Northrop	53
A15	Fatigue Crack Growth Rate Data for Pechiney 2091-T8X Plate L-T Orientation, Grumman	54
A16	Fatigue Crack Growth Rate Data for Pechiney 2091-T8X Plate T-L Orientation, Grumman	55

<b><u>FIGURE</u></b>		<b><u>PAGE</u></b>
A17	Fatigue Crack Growth Rate Data for Pechiney 2091-T8X Plate T-L Orientation, Grumman	56
A18	Fatigue Crack Growth Rate Data for Pechiney 2091-T8X Plate 45° Orientation, Grumman	57
A19	Fatigue Crack Growth Rate Data for Pechiney 2091-T8X Plate L-T Orientation, General Dynamics TX	58
A20	Fatigue Crack Growth Rate Data for Pechiney 2091-T8X Plate T-L Orientation, General Dynamics TX	59
A21	Fatigue Crack Growth Rate Data for Pechiney 2091-T8X Plate T-L Orientation, General Dynamics TX	60
B1	R-Curve Results for Pechiney 2091-T3 Sheet LT Orientation, General Dynamics CA	71
B2	R-Curve Results for Pechiney 2091-T3 Sheet LT Orientation, General Dynamics CA	73
B3	R-Curve Results for Pechiney 2091-T3 Sheet LT Orientation, General Dynamics CA	75
B4	R-Curve Results for Pechiney 2091-T3 Sheet TL Orientation, General Dynamics CA	77
B5	R-Curve Results for Pechiney 2091-T3 Sheet TL Orientation, General Dynamics CA	79
B6	R-Curve Results for Pechiney 2091-T3 Sheet TL Orientation, General Dynamics CA	81
B7	R-Curve Results for Pechiney 2091-T3 Sheet LT Orientation, Martin Marietta LA	83
B8	R-Curve Results for Pechiney 2091-T3 Sheet TL Orientation, Martin Marietta LA	83
B9	R-Curve Results for Pechiney 2091-T3 Sheet LT Orientation, Martin Marietta LA	84
B10	R-Curve Results for Pechiney 2091-T3 Sheet TL Orientation, Martin Marietta LA	84
B11	Fatigue Results for Pechiney 2091-T3 Sheet Longitudinal Orientation, R=0.1, Kt=1.0	91

<b><u>FIGURE</u></b>		<b><u>PAGE</u></b>
B12	Fatigue Results for Pechiney 2091-T3 Sheet Longitudinal Orientation, R=0.1, Kt=2.8	92
B13	Fatigue Results for Pechiney 2091-T3 Sheet Transverse Orientation, R=0.1, Kt=2.8	93
B14	Fatigue Crack Growth Rate Data for Pechiney 2091-T3 Sheet, L-T Orientation, McDonnell Douglas LA	94
B15	Fatigue Crack Growth Rate Data for Pechiney 2091-T3 Sheet, T-L Orientation, McDonnell Douglas LA	95
B16	R-Curve Results for Pechiney 2091-T8X Sheet L-T Orientation, Grumman	103
B17	R-Curve Results for Pechiney 2091-T8X Sheet T-L Orientation, Grumman	104
B18	Fatigue Crack Growth Rate Data for Pechiney 2091-T8X Sheet L-T Orientation, Grumman	106
B19	Fatigue Crack Growth Rate Data for Pechiney 2091-T8X Sheet T-L Orientation, Grumman	107
B20	Fatigue Crack Growth Rate Data for Pechiney 2091-T8X Sheet 45° Orientation, Grumman	108
B21	Fatigue Crack Growth Rate Data for Pechiney 2091-T8X Sheet L-T Orientation, Northrop	109
B22	Fatigue Crack Growth Rate Data for Pechiney 2091-T8X Sheet T-L Orientation, Northrop	110
B23	Fatigue Crack Growth Rate Data for Pechiney 2091-T8X Sheet L-T Orientation, General Dynamics TX	111
B24	Fatigue Crack Growth Rate Data for Pechiney 2091-T8X Sheet T-L Orientation, General Dynamics TX	112
C1	Pechiney 2091-T6 Precision Die Forging Dimensions	114
C2	Fatigue Crack Growth Rate Data for Pechiney 2091-T6 Forgings, L-T Orientation, Northrop	128
C3	Fatigue Crack Growth Rate Data for Pechiney 2091-T6 Forgings, T-L Orientation, Northrop	129
D1	Fatigue Results for Pechiney 8090-T651 T-Extrusion Longitudinal Orientation, R=0.1, Kt=2.8, LTV	138

<b>FIGURE</b>		<b>PAGE</b>
E1	Fatigue Results for 8090-T651 1" x 4" Extrusion (R=0.1, Kt=1.0, Longitudinal)	157
E2	Fatigue Results for 8090-T651 1" x 4" Extrusion (R=0.1, Kt=3.0, Longitudinal)	159
E3	Fatigue Crack Growth Rate Data for Alcan 8090-T8 1" x 4" Extrusion (L-T Orientation). Grumman	160
E4	Fatigue Crack Growth Rate Data for Alcan 8090-T8 1" x 4" Extrusion (T-L Orientation). Grumman	161
E5	Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (L-T Orientation). Northrop	162
E6	Fatigue Crack Growth Rate for Alcan 8090-T651 1" x 4" Extrusion (T-L Orientation). Northrop	163
E7	Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (L-T Orientation). U.S. Air Force	164
E8	Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (L-T Orientation). U.S. Air Force	165
E9	Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (L-T Orientation). U.S. Air Force	166
E10	Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (T-L Orientation). U.S. Air Force	167
E11	Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (T-L Orientation). U.S. Air Force	168
E12	Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (T-L Orientation). U.S. Air Force	169
E13	Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (L-T Orientation). NASA-Langley	170
E14	Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (L-T Orientation). NASA-Langley	171
E15	Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (T-L Orientation). NASA-Langley	172
E16	Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (T-L Orientation). NASA-Langley	173
E17	Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (T-L Orientation). NASA-Langley	174

<b>FIGURE</b>		<b>PAGE</b>
E18	FALSTAFF Spectrum Results for 8090-T651 Extrusion	175
E19	Crack Length Versus Flights for 8090-T651 Extrusion Under FALSTAFF Loading, Max Stress = 30 KSI	176
E20	Crack Length Versus Flights for 8090-T651 Extrusion Under Mini-TWIST Loading, Max Stress = 17 KSI	176
E21	Crack Length Versus Flights for 8090-T651 Extrusion Under Mini-TWIST Loading, Max Stress = 26 KSI	177
F1	Fatigue Results for 8090-T8771 Plate (Longitudinal Orientation). Air Force.	191
F2	Fatigue Crack Growth Rate Data for 8090-T8771 Plate (L-T Orientation). Martin Marietta.	192
F3	Fatigue Crack growth Rate Data for 8090-T8771 Plate (T-L Orientation). Martin Marietta.	193
F4	Fatigue Crack Growth Rate Data for 8090-T8771 Plate (S-T Orientation). Martin Marietta.	194
F5	Fatigue Crack Growth Rate Data for 8090-T8771 Plate (L-T Orientation and R=0.1). Air Force.	195
F6	Fatigue Crack Growth Rate Data for 8090-T8771 Plate (L-T Orientation and R=0.33). Air Force.	196
F7	Fatigue Crack Growth Rate Data for 8090-T8771 Plate (L-T Orientation, R=0.1 and High Humidity). Air Force.	197
F8	Fatigue Crack Growth Rate Data for 8090-T8771 Plate (L-T Orientation, R=0.33 and High Humidity). Air Force.	198
F9	Mini-TWIST Spectrum Crack Length vs Flights Data for 8090-T8771 Plate (L-T Orientation, Room Temperature, Lab Air and Maximum Stress=16.9 ksi). Air Force.	199
F10	Mini-TWIST Spectrum Crack Growth Rate vs Delta K Data for 8090-T8771 Plate (L-T Orientation, Room Temperature, Lab Air and Maximum Stress=16.9 ksi). Air Force.	200
F11	FALSTAFF Spectrum Crack Length vs Total Flights Data for 8090-T8771 Plate (L-T Orientation, Room Temperature, Lab Air and Maximum Stress=20 ksi). Air Force.	201
F12	FALSTAFF Spectrum Crack Growth Rate vs Delta K Data for 8090-T8771 Plate (L-T Orientation, Room Temperature, Lab Air and Maximum Stress=20 ksi). Air Force.	202

<b>FIGURE</b>		<b>PAGE</b>
G1	IN905XL Jack Fitting Precision Forging	204
G2	Fatigue Results for IN905XL Forging ( $R=0.1$ , $K_t=1.0$ ), Sikorsky	224
G3	Fatigue Results for IN905XL Forging ( $R=-1.0$ , $K_t=1.0$ ), Sikorsky	228
G4	Fatigue Results for IN905XL Forging ( $R=0.1$ , $K_t=3.0$ ), Sikorsky	231
G5	Fatigue Results for IN905XL Forging ( $R=-1.0$ , $K_t=3.0$ ), Sikorsky	235
G6	Fatigue Crack Growth Rate Data for IN905XL Forging (L-T Orientation, KGRAD -2.00 and 2.00). Northrop.	238
G7	Fatigue Crack Growth Rate Data for IN905XL Forging (L-T Orientation, KGRAD -4.00 and 4.00). Northrop.	239
G8	Fatigue Crack Growth Rate Data for IN905XL Forging (T-L Orientation, KGRAD -2.00 and 2.00). Northrop.	240
G9	Fatigue Crack Growth Rate Data for IN905XL Forging (T-L Orientation, KGRAD -4.00 and 4.00). Northrop.	241
G10	Fatigue Crack Growth Rate Data for IN905XL Forging (S-L Orientation, KGRAD -2.00 and 2.00). Northrop.	242
G11	Fatigue Crack Growth Rate Data for IN905XL Forging (S-L Orientation, KGRAD -2.00 , 2.00 and 2.00). Northrop.	243
G12	Fatigue Crack Growth Rate Data for Aged IN905XL Forging (L-T and T-L Orientation, $R=0.1$ , 6Hz, Lab Air and a third order regression fit to each data set). General Dynamics TX.	244
G13	Fatigue Crack Growth Rate Data for IN905XL Forging (WOL Specimen, L-T Orientation, $R=0.02$ and Lab Air) . McDonnell Aircraft MO.	245
G14	Fatigue Crack Growth Rate Data for IN905XL Forging (WOL Specimen, T-L Orientation, $R=0.02$ and Lab Air). McDonnell Aircraft MO.	246
G15	Mini-TWIST Spectrum Fatigue Crack Growth Rate Data. Air Force.	247
H1	AL905XL Back-Up Fitting Precision Forging	249

<b>FIGURE</b>		<b>PAGE</b>
H2	Fatigue Results for AL905XL Forging (Longitudinal Orientation, R=0.1, Kt=1.0). McDonnell Douglas Helicopter.	261
H3	Fatigue Crack Growth Rate Data for AL905XL Forging (L-T Orientation), Northrop, MCAIR, Air Force.	263
H4	Fatigue Crack Growth Rate Data for AL905XL Forging (K-decreasing Method, L-T Orientation). Northrop.	264
H5	Fatigue Crack Growth Rate Data for AL905XL Forging (T-L Orientation). Northrop, MCAIR, Air Force.	265
H6	Fatigue Crack Growth Rate Data for AL905XL Forging (K-decreasing method, T-L Orientation). Northrop.	266
H7	Fatigue Crack Growth Rate Data for AL905XL Forging (S-T Orientation), Northrop, MCAIR. Air Force	267
H8	FALSTAFF Spectrum Fatigue Crack Growth Rate Data for AL905XL Forging (L-S Orientation, Maximum Stress = 20 KSI, Lab Air and Room Temperature), Air Force	268
H9	Mini-TWIST Spectrum Fatigue Crack Growth Rate Data for AL905XL Forging (L-S Orientation, Maximum Stress=16.9 KSI, Lab Air and Room Temperature). Air Force.	269
I1	Hardness Profile through 2095-T8 Plate	289
I2	Ballistic Limit vs Armor Demand Data for 2095-T8 Plate	290
I3	Fatigue Results for 2095-T8 0.5 Inch Plate (R=-1, Kt=1.0 and Kt=3.0)	291
I4	Fatigue Results for 2095-T8 0.5 Inch Plate (R=0.1 and Kt=1.0)	294
I5	Fatigue Results for 2095-T8 0.5 Inch Plate (R=0.1 and Kt=3)	296
I6	Fatigue Crack Growth Data for 2095-T8 Plate (LT-LT Orientation, Specimen W45-1). Air Force.	298
I7	Fatigue Crack Growth Data for 2095-T8 Plate (LT-LT Orientation, Specimen W45-2). Air Force.	299
I8	Fatigue Crack Growth Data for 2095-T8 Plate (L-T and T-L Orientations). Northrop.	300
I9	Fatigue Crack Growth Data for 2095-T8 Plate (L-T Orientation, KGRAD -4.00 and 2.50). Northrop.	301
I10	Fatigue Crack Growth Data for 2095-T8 Plate (L-T Orientation, KGRAD 2.50). Northrop.	302

<b>FIGURE</b>		<b>PAGE</b>
I11	Fatigue Crack Growth Data for 2095-T8 Plate (T-L Orientation, KGRAD -4.00 and 2.50). Northrop.	303
I12	Fatigue Crack Growth Data for 2095-T8 Plate (T-L Orientation, KGRAD 2.50). Northrop.	304
I13	T-38 LIF Spectrum Fatigue Crack Growth Data for 2095-T8 Plate (Max Stress=38 ksi, Flaw = 0.01 inch). Northrop.	305
I14	T-38 LIF Spectrum Fatigue Crack Growth Data for 2095-T8 Plate (Max Stress= 38 ksi, Flaw = 0.05 inch). Northrop.	306
I15	T-38 LIF Spectrum Fatigue Crack Growth $da/dFH$ vs a Data for 2095-T8 Plate. Northrop.	307
J1	R-Curve Results for 2091-T3 0.063 Inch Sheet (L-T Orientation). Martin Marietta.	311
J2	R-Curve Results for 2091-T3 0.063 Inch Sheet (T-L Orientation). Martin Marietta.	311
J3	R-Curve Results for 2091-T3 0.063 Inch Sheet with Effective Crack Length Adjusted for Plastic Zone (L-T Orientation). Martin Marietta.	312
J4	R-Curve Results for 2091-T3 0.063 Inch Sheet with Effective Crack Length Adjusted for Plastic Zone (T-L Orientation). Martin Marietta.	313
J5	FALSTAFF Spectrum Crack Length vs Flights Data for 2091-T3 0.063 Inch Sheet. Air Force.	318
J6	FALSTAFF Spectrum Crack Growth Rate vs $K_{max}$ Data for 2091-T3 0.063 Inch Sheet. Air Force.	319
J7	Mini-TWIST Spectrum Crack Length vs Flights Data for 2091-T3 0.063 Inch sheet. Air Force.	320
J8	Mini-TWIST Spectrum Crack Growth Rate vs $K_{max}$ Data for 2091-T3 0.063 Inch Sheet. Air Force.	321
J9	Fatigue Crack Growth Rate Data for 2091-T8X 0.063 Inch Sheet Relative to 2024-T351 (L-T Orientation). Northrop.	334
J10	Fatigue Crack Growth Rate Data for 2091-T8 0.063 Inch Sheet Relative to 2024-T351 (T-L Orientation). Northrop.	335
J11	Fatigue Crack Growth Rate Data for 2091-T8 0.063 Inch Sheet (L-T Orientation). McDonnell Aircraft Company.	336

<b>FIGURE</b>		<b>PAGE</b>
J12	Fatigue Crack Growth Rate Data for 2091-T8 0.063 Inch Sheet (T-L Orientation). McDonnell Aircraft Company.	337
K1	R-Curve Results for 2091-T3 0.144 Inch Sheet (L-T Orientation). Martin Marietta.	347
K2	R-Curve Results for 2091-T3 0.144 Inch Sheet (T-L Orientation). Martin Marietta.	348
K3	R-Curve Results for 2091-T3 0.144 Inch Sheet with Effective Crack Length Adjusted for Plastic Zone (L-T Orientation). Martin Marietta.	349
K4	R-Curve Results for 2091-T3 0.144 Inch Sheet with Effective Crack Length Adjusted for Plastic Zone (T-L Orientation). Martin Marietta.	350
K5	R-Curve Results for 2091-T3 0.144 Inch Sheet (L-T Orientation). Air Force.	355
K6	R-Curve Results for 2091-T3 0.144 Inch Sheet (T-L Orientation). Air Force.	357
K7	R-Curve Results for 2091-T3 0.144 Inch Sheet (60° Orientation, Specimen 1). Air Force.	359
K8	R-Curve Results for 2091-T3 0.144 Inch Sheet (60° Orientation, Specimen 2). Air Force.	361
K9	R-Curve Results for 2091-T3 0.144 Inch Sheet (L-T Orientation, -321°F). Air Force	363
K10	Fatigue Results for 2091-T3 0.144 Inch Sheet (R=1.0, Kt=1.0). McDonnell Douglas Astronautics.	366
K11	Fatigue Results for 2091-T3 0.144 Inch Sheet (r=1.0, Kt=3.0). McDonnell Douglas Astronautics.	368
	2091-T3 0.144 Inch Sheet. Air Force.	369
K13	FALSTAFF Spectrum Crack Growth Rate vs Kmax Data for 2091-T3 0.144 Inch Sheet. Air force.	370
K14	Mini-TWIST Spectrum Fatigue Crack Length vs Flights Data for 2091-T3 0.144 Inch Sheet (Specimen #2091A912). Air Force.	371
K15	Mini-TWIST Spectrum Crack Growth Rate vs Kmax Data for 2091-T3 0.144 Inch Sheet (Specimen #2091A912). Air Force.	372
K16	Mini-TWIST Spectrum Fatigue Crack Length vs Flights Data for 2091-T3 0.144 Inch Sheet (Specimen #2091T34M). Air Force.	373

<b>FIGURE</b>		<b>PAGE</b>
K17	Mini-Twist Spectrum Crack Growth Rate vs Kmax Data for 2091-T3 0.144 Inch Sheet (Specimen #2091T34M). Air Force.	374
K18	Tear Strength to Yield Strength Ratio vs Yield Strength Data for 2091-T3 Aged 16/32 Hours at 335°F. General Dynamics.	382
K19	Fatigue Crack Growth Rates for 2091-T8X 0.144 Inch Sheet Relative to 2024-T351 (L-T Orientation). Northrop.	390
K20	Fatigue Crack Growth Rates for 2091-T8X 0.144 Inch Sheet Relative to 2024-T351 (T-L Orientation). Northrop.	391
L1	A Comparison of Delay Cycles Due to Fatigue Crack Growth Retardation for a 60 Percent Overload Cycle. Air Force.	398
L2	Delay Cycles Due to Fatigue Crack Growth Retardation for an 80 Percent Overload Cycle. Air Force.	399
L3	A Comparison of the Crack Closure Level Prior to the Application of a 60 Percent Overload Cycle. Air Force.	400
L4	Crack Velocity Versus Post-Overload Crack Extension for Alloy 2091-T83 Sheet. Air Force.	402
L5	Crack Velocity Versus Post-Overload Crack Extension for Alloy 2091-T81 Plate 0.144 Inch Thick Specimen. Air Force.	403
L6	Crack Velocity Versus Post-Overload Crack Extension for Alloy 2091-T81 Plate 0.250 Inch Thick Specimen. Air Force.	404
M1	8090-T8 Hat Extrusion Geometry	406
M2	8090-T8 L-Extrusion Geometry	406
M3	Fatigue Results for 8090-T8771 L-Extrusion (R=0.1 and Kt=1.0). Army.	422
M4	Fatigue Crack Growth Rates for 8090-T8771 L-Extrusion (L-T Orientation). Martin Marietta.	423
M5	Fatigue Crack Growth Rates for 8090-T8771 L-Extrusion (T-L Orientation). Martin Marietta.	424
M6	Fatigue Crack Growth Rates for 8090-T8771 L-Extrusion (S-T Orientation). Martin Marietta.	425
N1	Fatigue Results for 7064-T74511 Extrusion (Longitudinal Orientation). LTV.	436
N2	Fatigue Crack Growth Rate Data for Two 7064-T74511 Extrusion Specimens (L-T). Air Force.	437

<b><u>FIGURE</u></b>		<b><u>PAGE</u></b>
N3	Fatigue Crack Growth Rate Data for Two 7064-T74511 Extrusion Specimens (T-L). Air Force.	438
N4	Mini-TWIST Spectrum Fatigue Crack Length vs Flights Data for 7064-T74511 Extrusion. Air Force.	439
N5	Mini-TWIST Spectrum Fatigue Crack Growth Rate Data for 7064-T74511 Extrusion. Air Force.	440
N6	FALSTAFF Spectrum Fatigue Crack Length vs Flights Data for 7064-T74511 Extrusion. Air Force.	441
N7	FALSTAFF Spectrum Fatigue Crack Growth Rate Data for 7064-T74511 Extrusion. Air Force.	442
O1	Fatigue Data for 7064-T74 Forging (Longitudinal Orientation, R=0.1, Kt=1 and Kt=3). LTV.	459
O2	Fatigue Data for 7064-T74 Forging (Longitudinal Orientation, R=-1.0, and Kt=1). McDonnell Aircraft Company.	461
O3	Fatigue Crack Growth Rate Data for 7064-T74 Forging (T-L Orientation, WOL Type Specimen ). McDonnell Aircraft Company.	462
O4	Mini-TWIST Spectrum Fatigue Crack Length vs Flights Data for 7064-T74 Forging. Air Force.	463
O5	Mini-TWIST Spectrum Fatigue Fatigue Crack Growth Rate Data for 7064-T74 Forging. Air Force.	464
O6	FALSTAFF Spectrum Fatigue Crack Length vs Flights Data for 7064-T74 Forging. Air Force.	465
O7	FALSTAFF Spectrum Fatigue Crack Growth Rate Data for 7064-T74 Forging. Air Force.	466
P1	R-Curve Data for CW67 Sheet (L-T Orientation). Martin Marietta.	477
P2	R-Curve Effective Crack Length Adjusted for Plastic Zone (L-T Orientation). Martin Marietta	477
P3	Fatigue Crack Growth Rate Data for CW67 Sheet (L-T Orientation, R=0.1, Lab Air and RT). McDonnell Aircraft Company.	480
P4	Fatigue Crack Growth Rate Data for CW67 Sheet (L-T Orientation, R=0.33, Lab Air and RT. McDonnell Aircraft Company.	481
P5	Fatigue Crack Growth Rate Data for CW67 Sheet (T-L Orientation, R=0.1, Lab Air and RT). McDonnell Aircraft Company.	482

<b><u>FIGURE</u></b>		<b><u>PAGE</u></b>
P6	Fatigue Crack Growth Rate Data for CW67 Sheet (T-L Orientation, R=0.33, Lab Air and RT). McDonnell Aircraft Company.	483
Q1	R-Curve Data for CW67 Plate (L-T Orientation). Martin Marietta.	486
Q2	R-Curve Effective Crack Length Adjusted for Plastic Zone Data for CW67 Plate (L-T Orientation). Martin Marietta.	486
R1	Fatigue Crack Growth Rate Data for CW67 Extrusion (L-T Orientation and R=0.1). McDonnell Aircraft Company.	498
R2	Fatigue Crack Growth Rate Data for CW67 Extrusion (L-T Orientation and R=0.33). McDonnell Aircraft Company.	499
R3	Fatigue Crack Growth Rate Data for CW67 Extrusion (T-L Orientation and R=0.1). McDonnell Aircraft Company.	500
R4	Fatigue Crack Growth Rate Data for CW67 Extrusion (T-L Orientation and R=0.33). McDonnell Aircraft Company.	501
R5	Fatigue Crack Growth Rate Data for CW67 Extrusion (L-T Orientation). Air Force.	502
R6	Fatigue Crack Growth Rate Data for CW67 Extrusion (T-L Orientation). Air Force.	503
R7	Fatigue Crack growth Rate Data for CW67 Extrusion (L-T Orientation and High Humidity). Air Force.	504
R8	Fatigue Crack Growth Rate Data for CW67 Extrusion (L-T Orientation and Specimen GLT-1). LTV.	505
R9	Fatigue Crack Growth rate Data for CW67 Extrusion (L-T Orientation and Specimen GLT-2). LTV.	506
R10	Fatigue Crack Growth Rate Data for CW67 Extrusion (L-T Orientation and Specimen GLT-3). LTV.	507
R11	Fatigue Crack Growth Rate Data for CW67 Extrusion (T-L Orientation and Specimen GTL-1). LTV.	508
R12	Fatigue Crack Growth Rate Data for CW67 Extrusion (T-L Orientation and Specimen GTL-2). LTV.	509
R13	Fatigue Crack Growth Rate Data for CW67 Extrusion (T-L Orientation and Specimen GTL-3). LTV.	510
R14	Mini-TWIST Spectrum Fatigue Crack Length vs Flights Data for CW67 Extrusion (CSP-2). Air Force.	511

<b><u>FIGURE</u></b>		<b><u>PAGE</u></b>
R15	Mini-TWIST Spectrum Fatigue Crack Growth Rate Data for CW67 Extrusion (CSP-2). Air Force.	512
R16	Mini-TWIST Spectrum Fatigue Crack Length vs Flights Data for CW67 Extrusion (CSP-4). Air Force.	513
R17	Mini-TWIST Spectrum Fatigue Crack Growth Rate Data for CW67 Extrusion (CSP-4). Air Force.	514
R18	FALSTAFF Spectrum Fatigue Crack Length vs Flights (CSP-1). Air Force.	515
R19	FALSTAFF Spectrum Fatigue Crack Growth Rate Data for CW67 Extrusion (CSP-1). Air Force.	516
R20	FALSTAFF Spectrum Fatigue Crack Length vs Flights (CSP-3). Air Force.	517
R21	FALSTAFF Spectrum Fatigue Crack Growth Rate Data for CW67 Extrusion (CSP-3). Air Force.	518
S1	Fatigue Crack Growth Rate Data for CW67 Forging (L-T Orientation). Air Force.	529
S2	Fatigue Crack Growth Rate Data for CW67 Forging (T-L Orientation). Air Force.	530
S3	Fatigue crack Growth Rate Data for CW67 Forging (S-T Orientation). Air Force.	531
S4	Comparison of CW67 Forging and 7050 Plate Mini-TWIST Spectrum Fatigue Crack Growth Rate Data. Air Force.	532
S5	Comparison of CW67 Forging and 7050 Plate FALSTAFF Spectrum Fatigue Crack Growth Rate Data. Air Force.	533

## LIST OF TABLES

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
A1      Tensile Results at t/2 Location for Pechiney 2091-T351 Plate, Longitudinal Orientation	9
A2      Tensile Results at t/2 Location of Pechiney 2091-T351 Plate, Transverse Orientation	10
A3      Compression Results at t/2 Location for Pechiney 2091-T351 Plate, Longitudinal Orientation	11
A4      Compression Results at t/2 Location for Pechiney 2091-T351 Plate, Transverse Orientation	12
A5      Rivet Shear Results for Pechiney 2091-T351 Plate, Longitudinal Orientation	13
A6      Rivet Shear Results for Pechiney 2091-T351 Plate, Transverse Orientation	13
A7      Amsler Double Shear Results for Pechiney 2091-T351 Plate	14
A8      Bearing Results for Pechiney 2091-T351 Plate, Longitudinal Orientation, $e/D=1.5$	15
A9      Bearing Results for Pechiney 2091-T351 Plate, Transverse Orientation, $e/D=1.5$	15
A10     Bearing Results for Pechiney 2091-T351 Plate, Longitudinal Orientation, $e/D=2.0$	16
A11     Bearing Results for Pechiney 2091-T351 Plate, Transverse Orientation, $e/D=2.0$	16
A12     Fracture Toughness Results for Pechiney 2091-T351 Plate, L-T Orientation	17
A13     Fracture Toughness Results for Pechiney 2091-T351 Plate, T-L Orientation	18
A14     R-Curve Data for 2091 Specimen No. 1, Longitudinal Orientation	21
A15     R-Curve Data for 2091 Specimen No. 2, Longitudinal Orientation	22
A16     R-Curve Data for 2091 Specimen No. 3, Transverse Orientation	23
A17     Fatigue Results for Pechiney 2091-T351 Plate $R=0.1$ , $K_t=1.0$	24
A18     Tensile Results at t/2 Location for Pechiney 2091-T8X Plate, Longitudinal Orientation	32

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
A19      Tensile Results at t/2 Location for Pechiney 2091-T8X Plate, Transverse Orientation	33
A20      Tensile Results at t/2 Location for Pechiney 2091-T8X Plate, 45° Orientation	34
A21      Tensile Results at t/10 Location for Pechiney 2091-T8X Plate, Longitudinal Orientation	35
A22      Tensile Results at t/10 Location for Pechiney 2091-T8X Plate, Transverse Orientation	35
A23      Tensile Results at t/2 Location with 100 Hours Exposure for Pechiney 2091-T8X Plate, Longitudinal Orientation	36
A24      Compression Results at t/2 Location for Pechiney 2091-T8X Plate, Longitudinal Orientation	37
A25      Compression Results at t/2 Location for Pechiney 2091-T8X Plate, Transverse Orientation	38
A26      Compression Results at t/2 Location for Pechiney 2091-T8X Plate, 45° Orientation	38
A27      Rivet Shear Results for Pechiney 2091-T8X Plate, L-S Orientation	39
A28      Rivet Shear Results for Pechiney 2091-T8X Plate, T-S Orientation	39
A29      Slotted Shear Results for Pechiney 2091-T8X Plate, Longitudinal Orientation	40
A30      Slotted Shear Results for Pechiney 2091-T8X Plate, Transverse Orientation	40
A31      Bearing Results for Pechiney 2091-T8X Plate, Longitudinal Orientation, e/D=1.5	41
A32      Bearing Results for Pechiney 2091-T8X Plate, Transverse Orientation, e/D=1.5	42
A33      Bearing Results for Pechiney 2091-T8X Plate, Longitudinal Orientation, e/D=2.0	43
A34      Bearing Results for Pechiney 2091-T8X Plate, Transverse Orientation, e/D=2.0	44
A35      Fracture Toughness Results for Pechiney 2091-T8X Plate, L-T Orientation	45

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
A36 Fracture Toughness Results for Pechiney 2091-T8X Plate, T-L Orientation	46
A37 R-Curve Results for Pechiney 2091-T8X Plate General Dynamics, TX	47
A38 Smooth Fatigue Results for Pechiney 2091-T8X Plate R=0.1, Kt=1.0, Longitudinal Orientation	48
A39 Notched Fatigue Results for Pechiney 2091-T8X Plate R=0.1, Kt=3.0, Longitudinal Orientation	50
B1 Tensile Results for Pechiney 2091-T3 Sheet, Longitudinal Orientation	63
B2 Tensile Results for Pechiney 2091-T3 Sheet, Transverse Orientation	64
B3 Compression Results for Pechiney 2091-T3 Sheet, Longitudinal Orientation	65
B4 Compression Results for Pechiney 2091-T3 Sheet, Transverse Orientation	65
B5 Punch Shear Results for Pechiney 2091-T3 Sheet, Short Transverse Orientation	66
B6 Slotted Shear Results for Pechiney 2091-T3, Longitudinal Orientation	66
B7 Slotted Shear Results for Pechiney 2091-T3, T-L Orientation	67
B8 Bearing Results for Pechiney 2091-T3 Sheet, Longitudinal Orientation, c/D=1.5	68
B9 Bearing Results for Pechiney 2091-T3 Sheet, Transverse Orientation, c/D=1.5	68
B10 Bearing Results for Pechiney 2091-T3 Sheet, Longitudinal Orientation, c/D=2.0	69
B11 Bearing Results for Pechiney 2091-T3 Sheet, Transverse Orientation, c/D=2.0	69
B12 R-Curve Results for Pechiney 2091-T3 Sheet, LT Orientation, General Dynamics CA	70
B13 R-Curve Results for Pechiney 2091-T3 Sheet, LT Orientation, General Dynamics CA	72
B14 R-Curve Results for Pechiney 2091-T3 Sheet, LT Orientation, General Dynamics CA	74
B15 R-Curve Results for Pechiney 2091-T3 Sheet, TL Orientation, General Dynamics Ca	76

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
B16 R-Curve Results for Pechiney 2091-T3 Sheet, TL Orientation, General Dynamics CA	78
B17 R-Curve Results for Pechiney 2091-T3 Sheet, TL Orientation, General Dynamics CA	80
B18 R-Curve Results for Pechiney 2091-T3 Sheet, LT and TL Orientation, MCAIR	82
B19 R-Curve Results for Pechiney 2091-T3 Sheet, LT Orientation, Martin Marietta LA	85
B20 R-Curve Results for Pechiney 2091-T3 Sheet, LT Orientation, Martin Marietta LA	86
B21 R-Curve Results for Pechiney 2091-T3 Sheet, TL Orientation, Martin Marietta LA	87
B22 R-Curve Results for Pechiney 2091-T3 Sheet, TL Orientation, Martin Marietta LA	88
B23 Fatigue Results for Pechiney 2091-T3 Sheet, Longitudinal Orientation, R=0.1, Kt=1.0	89
B24 Fatigue Results for Pechiney 2091-T3 Sheet, Longitudinal Orientation, R=0.1, Kt=3.0	89
B25 Fatigue Results for Pechiney 2091-T3 Sheet, Longitudinal Orientation, R=0.1, Kt=2.8	90
B26 Fatigue Results for Pechiney 2091-T3 Sheet, Transverse Orientation, R=0.1, Kt=2.8	90
B27 Tensile Results for Pechiney 2091-T8X Sheet, Longitudinal Orientation	97
B28 Tensile Results for Pechiney 2091-T8X Sheet, Transverse Orientation	97
B29 Compression Results for Pechiney 2091-T8X Sheet, Longitudinal Orientation	98
B30 Compression Results for Pechiney 2091-T8X Sheet, Transverse Orientation	98
B31 Compression Results for Pechiney 2091-T8X Sheet, 45° Orientation	99
B32 Slotted Shear Results for Pechiney 2091-T8X Sheet, Longitudinal Orientation	100

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
B33      Slotted Shear Results for Pechiney 2091-T8X Sheet, Transverse Orientation	100
B34      Bearing Results for Pechiney 2091-T8X Sheet, Longitudinal Orientation, $e/D=1.5$	101
B35      Bearing Results for Pechiney 2091-T8X Sheet, Transverse Orientation, $e/D=1.5$	101
B36      Bearing Results for Pechiney 2091-T8X Sheet, Longitudinal Orientation, $e/D=2.0$	102
B37      Bearing Results for Pechiney 2091-T8X Sheet, Transverse Orientation, $e/D=2.0$	102
B38      R-Curve Results for Pechiney 2091-T8X Sheet, L-T and T-L Orientations, General Dynamics TX	105
C1        Tensile Results at $t/2$ Locations for Pechiney 2091-T6 Forgings, Longitudinal Orientation	115
C2        Tensile Results at $t/2$ Locations for Pechiney 2091-T6 Forgings, Transverse Orientation	116
C3        Tensile Results at $t/2$ Locations for Pechiney 2091-T6 Forgings, Short Transverse Orientation	117
C4        Compression Results at $t/2$ Locations for Pechiney 2091-T6 Forgings, Longitudinal Orientation	118
C5        Compression at $t/2$ Locations for Pechiney 2091-T6 Forgings, Transverse Orientation	119
C6        Amsler Double Shear Results for Pechiney 2091-T6 Forgings, L-S Orientation	120
C7        Amsler Double Shear Results for Pechiney 2091-T6 Forgings, T-S Orientation	121
C8        Slotted Shear Results for Pechiney 2091-T6 Forgings, Longitudinal Orientation	122
C9        Bearing Results for Pechiney 2091-T6 Forgings, Longitudinal Orientation, $e/D=1.5$	123
C10      Bearing Results for Pechiney 2091-T6 Forgings, Longitudinal Results, $e/D=2.0$	124
C11      Bearing Results for Pechiney 2091-T6 Forgings, Transverse Orientation, $e/D=2.0$	125

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
C12      Fracture Toughness Results for Pechiney 2091-T6 Forgings, L-T Orientation	126
C13      Fracture Toughness Results for Pechiney 2091-T6 Forgings, T-L Orientation	127
D1        Tensile Results for Pechiney 8090-T651 T-Extrusion, Longitudinal Orientation	131
D2        Tensile Results for Pechiney 8090-T651 T-Extrusion, Transverse Orientation	131
D3        Compression Results for Pechiney 8090-T651 T-Extrusion, Longitudinal Orientation	132
D4        Slotted Shear Results for Pechiney 8090-T651 T-Extrusion, Longitudinal Orientation	133
D5        Slotted Shear Results for Pechiney 8090-T651 T-Extrusion, Transverse Orientation	133
D6        Iosipescu Shear Results for Pechiney 8090-T651 T-Extrusion, Longitudinal Orientation	134
D7        Iosipescu Shear Results for Pechiney 8090-T651 T-Extrusion, Transverse Orientation	134
D8        Bearing Results for Pechiney 8090-T651 T-Extrusion, Longitudinal Orientation, $c/D=1.5$	135
D9        Bearing Results for Pechiney 8090-T651 T-Extrusion, Longitudinal Orientation, $c/D=2.0$	136
D10      Fatigue Results for Pechiney 8090-T651 T-extrusion, Longitudinal Orientation, $R=0.1$ , $K_t=2.8$	137
E1        Tensile Results at $t/2$ Location for Alcan 8090-T651 Extrusion, Longitudinal Orientation, Varying Test Temperatures	140
E2        Tensile Results at $t/2$ Location for Alcan 8090-T651 Extrusion, Longitudinal Orientation, Varying Test Temperatures	141
E3        Tensile Results at $t/2$ Location for Alcan 8090-T651 Extrusion, Long Transverse Orientation	142
E4        Tensile Results at $t/2$ Location for Alcan 8090-T651 Extrusion, Long Transverse Orientation, Varying Test Temperatures	143
E5        Tensile Results at $t/2$ Location for Alcan 8090-T651 Extrusion, Short Transverse Orientation	144

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
E6      Tensile Results at t/10 Location for Alcan 8090-T651 Extrusion, Longitudinal Orientation	145
E7      Tensile Results at t/10 Location for Alcan 8090-T651 Extrusion, Long Transverse Orientation	145
E8      Tensile Results at t/2 Location for Alcan 8090-T651 Extrusion, Aged 100 Hrs at 350°F	146
E9      Notch Tensile results at t/2 Location for Alcan 8090-T651 Extrusion	147
E10     Compression Results for Alcan 8090-T651 Extrusion, Longitudinal Orientation	148
E11     Compression Results for Alcan 8090-T651 Extrusion, Long Transverse Orientation	148
E12     Rivet Shear Results for Alcan 8090-T651 Extrusion, L-S Orientation	149
E13     Rivet Shear Results for Alcan 8090-t651 Extrusion, T-S Orientation	149
E14     Amsler Double Shear Results for Alcan 8090-T651 Extrusion, L-S Orientation	150
E15     Amsler Double Shear Results for Alcan 8090-T651 Extrusion, T-S Orientation	150
E16     Bearing Results for Alcan 8090-T651 Extrusion, c/D=1.5, Longitudinal Orientation	151
E17     Bearing Results for Alcan 8090-T651 Extrusion, c/D=1.5, Long Transverse Orientation	151
E18     Bearing Results for Alcan 8090-T651 Extrusion, c/D=2.0, Longitudinal Orientation	152
E19     Bearing Results for Alcan 8090-t651 Extrusion, c/D=2.0, Long Transverse Orientation	152
E20     Fracture Toughness Results for Alcan 8090-T651 Extrusion L-T Orientation	153
E21     Fracture Toughness Results for Alcan 8090-T651 Extrusion T-L Orientation	154
E22     Stress Corrosion Cracking Results for Alcan 8090-T651 Extrusion T-L Orientation	155

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
E23      Fatigue Results for Alcan 8090-T651 Extrusion, R=0.1, Kt=1.0, Longitudinal Orientation	156
E24      Fatigue Results for Alcan 8090-T651 Extrusion, R=0.1, Kt=3.0, Longitudinal Orientation	158
E25      Tensile Results at t/2 Location for Alcan 8090-T8 Extrusion	178
E26      Compression Results at t/2 Location for Alcan 8090-T8 Extrusion	179
E27      Fracture Toughness Results for Alcan 8090-T8 Extrusion	180
F1        Tensile Results at t/2 Location for Alcan 8090-T8771 Plate, Longitudinal Orientation	182
F2        Tensile Results at t/2 Location for Alcan 8090-T8771 Plate 45 Degree Orientation	182
F3        Tensile Results at t/2 Location for Alcan 8090-T8771 Plate, Long Transverse Orientation	183
F4        Tensile results at t/2 Location for Alcan 80909-T8771 Plate, Short Transverse Orientation	183
F5        Compression results at t/2 Location for Alcan 8090-T8771 Plate, Longitudinal Orientation	184
F6        Compression Results at t/2 Location for Alcan 8090-T8771 Plate, Long Transverse Orientation	184
F7        Compression Results at t/2 Location for Alcan 8090-T8771 Plate, Short Transverse Orientation	185
F8        Amsler Double Shear Results at t/2 Location for Alcan 8090-T8771 Plate, T-L Orientation	186
F9        Bearing Results at t/2 Location for Alcan 8090-T8771 Plate, Longitudinal Orientation and e/D=1.5	187
F10      Bearing Results at t/2 Location for Alcan 8090-T8771 Plate, Long Transverse Orientation and e/D=1.5	187
F11      Fracture Toughness Results for Alcan 8090-T8771 Plate, L-T Orientation	188
F12      Fracture Toughness Results for Alcan 8090-T8771 Plate, S-L Orientation	188
F13      Fracture Toughness Results for Alcan 8090-T8771 Plate, T-L Orientation	189

<b><u>TABLE</u></b>		<b><u>PAGE</u></b>
F14	Fracture Toughness Results for Alcan 8090-T8771 Plate, S-T Orientation	189
F15	Fatigue Results with $R=0.1$ and $K_t=1.0$ for Alcan 8090-T8771 Plate, Longitudinal Orientation	190
F16	Fatigue Results with $R=0.1$ and $K_t=3.0$ for Alcan 8090-T8771 Plate, Longitudinal Orientation	190
G1	Tensile Results for IN905XL Forging, Longitudinal Orientation	205
G2	Tensile Results for IN905XL Forging, Long Transverse Orientation	206
G3	Tensile Results for IN905XL Forging, Short Transverse Orientation	207
G4	Tensile Results for Heat Treated IN905XL Forgings, Longitudinal Orientation	208
G5	Tensile Results for Heat Treated IN905XL Forgings, Long Transverse Orientation	208
G6	Compression Results for IN905XL Forging, Longitudinal Orientation	209
G7	Compression Results for IN905XL Forging, Long Transverse Orientation	210
G8	Compression Results for IN905XL Forging, Short Transverse Orientation	211
G9	Compression Results for Heat Treated IN905XL Forging, Longitudinal Orientation	212
G10	Compression Results for Heat Treated IN905XL Forging, Long Transverse Orientation	212
G11	Iosipescu Shear Results for IN905XL Forging, Longitudinal Orientation	213
G12	Iosipescu Shear Results for IN905XL Forging, Long Transverse Orientation	213
G13	Amsler Double Shear Results for Heat Treated IN905XL Forging, L-S Orientation	214
G14	Amsler Double Shear Results for IN905XL Forging, L-S Orientation	214
G15	Amsler Double Shear Results for IN905XL Forging, T-S Orientation	215

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
G16      Slotted Shear Results for IN905XL, Longitudinal Orientation	215
G17      Bearing Results for IN905XL Forging, Longitudinal Orientation ( $c/D=1.5$ )	216
G18      Bearing Results for IN905XL Forging, Long Transverse Orientation ( $c/D=1.5$ )	216
G19      Bearing Results for IN905XL Forging, Longitudinal Orientation ( $c/D=2.0$ )	217
G20      Bearing Results for Heat Treated IN905XL Forging, Longitudinal Orientation ( $c/D=2.0$ )	217
G21      Bearing Results for Heat Treated IN905XL Forging, Long Transverse Orientation( $c/D=2.0$ )	218
G22      Bearing Results for Heat Treated IN905XL Forging, Long Transverse ( $c/D=2.0$ )	218
G23      Fracture Toughness Results for IN905XL Forging, L-T Orientation	219
G24      Fracture Toughness Results for IN905XL Forging, T-L Orientation	220
G25      Fracture Toughness Results for IN905XL Forging, T-S Orientation	221
G26      Fracture Toughness Results for IN905XL Forging, S-T Orientation	222
G27      Fracture Toughness Results for IN905XL Forging, S-L Orientation	222
G28      Fracture Toughness Results for Heat Treated IN905XL Forging, L-T Orientation	223
G29      Fracture Toughness Results for Heat Treated IN905XL Forging, T-L Orientation	223
G30      Fatigue Results with $R=0.1$ and $K_t=1.0$ for IN905XL Forging, Longitudinal Orientation	225
G31      Fatigue Results with $R=0.1$ and $K_t=1.0$ for IN905XL Forging, Long Transverse Orientation	226
G32      Fatigue Results with $R=0.1$ and $K_t=1.0$ for IN905XL Forging, Short Transverse Orientation	227

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
G33      Fatigue Results with $R=-1.0$ and $K_t=1.0$ for IN905XL Forging, Longitudinal Orientation	229
G34      Fatigue Results with $R=-1.0$ and $K_t=1.0$ for IN905XL Forging, Long Transverse Orientation	230
G35      Fatigue Results with $R=0.1$ and $K_t=3.07$ for IN905XL Forging, Longitudinal Orientation	232
G36      Fatigue Results with $R=0.1$ and $K_t=3.07$ for IN905XL Forging, Long Transverse Orientation	233
G37      Fatigue Results with $R=0.1$ and $K_t=3.07$ for IN905XL Forging, Short Transverse Orientation	234
G38      Fatigue Results with $R=-1.0$ and $K_t=3.07$ for IN905XL Forging, Longitudinal Orientation	236
G39      Fatigue Results with $R=-1.0$ and $K_t=3.07$ for IN905XL Forging, Long Transverse Orientation	237
H1        Tensile Results for AL905XL Forging, Longitudinal Orientation	250
H2        Tensile Results for AL905XL Forging, Transverse Orientation	251
H3        Tensile Results for AL905XL Forging, Short Transverse Orientation	252
H4        Compression Results for AL905XL Forging, Longitudinal Orientation	253
H5        Compression Results for AL905XL Forging, Transverse Orientation	254
H6        Compression Results for AL905XL Forging, Short Transverse Orientation	254
H7        Amsler Double Shear Results for AL905XL Forging L-S Orientation	255
H8        Pin Shear Results for AL905XL Forging, L-S Orientation	255
H9        Bearing Results for AL905XL Forging, Longitudinal Orientation, $c/D=1.5$	256
H10      Bearing Results for AL905XL Forging, Longitudinal Orientation, $c/D=2.0$	256
H11      Fracture Toughness Results for AL905XL Forging, L-T Orientation	257

<b>TABLE</b>		<b>PAGE</b>
H12	Fracture Toughness Results for AL905XL Forging, T-L Orientation	258
H13	Fracture Toughness Results for AL905XL Forging, S-L Orientation	259
H14	Fracture Toughness Results for AL905XL Forging, S-T Orientation	260
H15	Fatigue Results for AL905XL Forging, (Longitudinal Orientation, R=0.1, Kt=1.0)	262
H16	Stress Corrosion Properties for AL905 XL Forging, Wyman Gordon	270
I1	Tensile Results for 2095-T8 Plate, Longitudinal Orientation	272
I2	Tensile Results for 2095-T8 Plate, Long Transverse Orientation	273
I3	Tensile Results for 2095-T8 Plate, 45 Degree Orientation	274
I4	Tensile Results for 2095-T8 Plate, Variable Temperatures	274
I5	Tensile Results for 2095-T8 Plate, 1000 HR Exposure at 350°F	275
I6	Compression Results for 2095-T8 Plate, Longitudinal Orientation	276
I7	Compression Results for 2095-T8 Plate, Long Transverse Orientation	277
I8	Compression Results for 2095-T8 Plate, 45 Degree Orientation	278
I9	Compression Ultimate Strength Results for 2095-T8 Plate	278
I10	Pin Shear Results for 2095-T8 Plate, Longitudinal Orientation	279
I11	Rivet Shear Results for 2095-T8 Plate, Long Transverse Orientation	279
I12	Torsional Shear Results for 2095-T8 Plate, Longitudinal and Long Transverse Orientation	280
I13	Amsler Double Shear Results for 2095-T8 Plate, L-S and T-S Orientation	281
I14	Bearing Results for 2095-T8 Plate, Longitudinal Orientation, $c/D=1.5$	282
I15	Bearing Results for 2095-T8 Plate, 45 Degree Orientation, $c/D=1.5$	282
I16	Bearing Results for 2095-T8 Plate, Long Transverse Orientation, $c/D=1.5$	283

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
I17      Bearing Results for 2095-T8 Plate, Longitudinal Orientation, $c/D=2.0$	284
I18      Bearing Results for 2095-T8, 45 Degree Orientation, $c/D=2.0$	284
I19      Bearing Results for 2095-T8 Plate, Long Transverse Orientation, $c/D=2.0$	285
I20      Fracture Toughness Results for 2095-T8 Plate, L-T Orientation	286
I21      Fracture Toughness Results for 2095-T8 Plate, T-L Orientation	287
I22      Fracture Toughness Results for 2095-T8 Plate, 45 Degree Orientation	288
I23      Hardness & Conductivity Results for 2095-T8 Plate	289
I24      Fatigue Results with $R=-1.0$ and $K_t=1.0$ for 2095-T8 Plate, Longitudinal Orientation	292
I25      Fatigue Results with $R=-1.0$ and $K_t=3.0$ for 2095-T8 Plate, Longitudinal Orientation	292
I26      Fatigue Results with $R=-1.0$ and $K_t=3.0$ for 2095-T8 Plate, Long Transverse Orientation	293
I27      Fatigue Results with $R=0.1$ and $K_t=1.0$ for 2095-T8 Plate, Longitudinal Orientation	295
I28      Fatigue Results with $R=0.1$ and $K_t=3.0$ for 2095-T8 Plate, Longitudinal Orientation	297
J1        Tensile Results for 2091-T3 0.063 Inch Sheet, Longitudinal Orientation	309
J2        Tensile Results for 2091-T3 0.063 Inch Sheet, 45 Degree Orientation	309
J3        Tensile Results for 2091-T3 0.063 Inch Sheet, 60 Degree Orientation	310
J4        Tensile results for 2091-T3 0.063 Inch Sheet, Long Transverse Orientation	310
J5        R-Curve Data Associated with Figures J1 and J3 (Specimen 1)	314
J6        R-Curve Data Associated with Figures J1 and J3 (Specimen 2)	315
J7        R-curve Data Associated with Figures J2 and J4 (Specimen 3)	316
J8        R-Curve Data Associated with Figures J2 and J4 (Specimen 4)	317

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
J9      Tensile Results for 2091-T8 0.063 Inch Sheet, Longitudinal Orientation	322
J10     Tensile results for 2091-T8 0.063 Inch Sheet, 45 Degree Orientation	322
J11     Tensile Results for 2091-T8 0.063 Inch Sheet, Long Transverse Orientation	323
J12     Compression Results for 2091-T8 0.063 Inch Sheet, Longitudinal Orientation	324
J13     Compression Results for 2091-T8 0.063 Inch Sheet, 45 degree Orientation	324
J14     Compression Results for 2091-t8 0.063 Inch Sheet, Long Transverse Orientation	325
J15     Slotted Shear Results for 2091-T8 0.063 Inch Sheet, Longitudinal Orientation	326
J16     Slotted Shear Results for 2091-T8 0.063 Inch Sheet, Long Transverse Orientation	326
J17     Bearing Results for 2091-T8 0.063 Inch Sheet, Longitudinal Orientation and $e/D=1.5$	327
J18     Bearing Results for 2091-T8 0.063 Inch Sheet, Long Transverse Orientation and $e/D=1.5$	327
J19     Bearing Results for 2091-T8 0.063 Inch Sheet, Longitudinal Orientation and $e/D=2.0$	328
J20     Bearing Results for 2091-T8 0.063 Inch Sheet, Long Transverse Orientation and $e/D=2.0$	328
J21     R-Curve Fracture Toughness Results for 2091-T8X 0.063 Sheet, Northrop	329
J22     R-Curve Fracture Toughness Results for 2091-T8 0.063 Sheet, L-T Specimen 1, McDonnell Aircraft Co.	330
J23     R-Curve Fracture Toughness Results for 2091-T8 0.063 Sheet, L-T Specimen 2, McDonnell Aircraft Co.	331
J24     R-Curve Fracture Toughness Results for 2091-T8 0.063 Sheet, T-L Specimen 1, McDonnell Aircraft Co.	332
J25     R-Curve Fracture Toughness Results for 2091-T8 0.063 Sheet, T-L Specimen 2, McDonnell Aircraft Co.	333

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
K1      Tensile Results for 2091-T3 0.144 Inch Sheet, Longitudinal Orientation	339
K2      Tensile Results for 2091-T3 0.144 Inch Sheet, 30 Degree Orientation	339
K3      Tensile Results for 2091-T3 0.144 Inch Sheet, 45 Degree Orientation	340
K4      Tensile Results for 2091-T3 0.144 Inch Sheet, 60 Degree Orientation	340
K5      Tensile Results for 2091-T3 0.144 Inch Sheet, Long Transverse Orientation	341
K6      Tensile Results for 2091-T3 0.144 Inch Sheet, Longitudinal Orientation, -320°F	341
K7      Tensile Results for 2091-T3 0.144 Inch Sheet, Long Transverse Orientation, -320°F	342
K8      Compression Results for 2091-T3 0.144 Inch Sheet, Longitudinal Orientation	343
K9      Compression Results for 2091-T3 0.144 Inch Sheet, Long Transverse Orientation	343
K10     Compression Results for 2091-T3 0.144 Inch Sheet, Longitudinal Orientation, -320°F	344
K11     Compression Results for 2091-T3 0.144 Inch Sheet, Long Transverse Orientation, -320°F	344
K12     Bearing Results for 2091-T3 0.144 Inch Sheet, Longitudinal Orientation and $e/D=1.5$	345
K13     Bearing Results for 2091-T3 0.144 Inch Sheet, Long Transverse Orientation and $e/D=1.5$	345
K14     Bearing Results for 2091-T3 0.144 Inch Sheet, Longitudinal Orientation and $e/D=2.0$	346
K15     Bearing Results for 2091-T3 0.144 Inch Sheet, Long Transverse Orientation and $e/D=2.0$	346
K16     R-Curve Data Associated with Figures K1 and K3 (Specimen 3)	351
K17     R-Curve Data Associated with Figures K1 and K3 (Specimen 4)	352
K18     R-Curve Data Associated with Figures K2 and K4 (Specimen 1)	353

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
K19 R-Curve Data Associated with Figures K2 and K4 (Specimen 2)	354
K20 R-Curve Data Associated with Figure K5 (L-T Orientation)	356
K21 R-Curve Data Associated with Figure K6 (T-L Orientation)	358
K22 R-Curve Data Associated with Figure K7 (60° Orientation, Specimen 1)	360
K23 R-Curve Data Associated with Figure K8 (60° Orientation, Specimen 2)	362
K24 R-Curve Data Associated with Figure K9 (L-T Orientation, -321°F)	364
K25 Fatigue Results with R=0.1 and Kt=1.0 for 2091-T3 0.144 Inch Sheet (Longitudinal Orientation)	365
K26 Fatigue Results with R=0.1 and Kt=1.0 for 2091-T3 0.144 Inch Sheet (Long Transverse Orientation)	365
K27 Fatigue Results with R=0.1 and Kt=3.0 for 2091-T3 0.144 Inch Sheet (Longitudinal Orientation)	367
K28 Fatigue Results with R=0.1 and Kt=3.0 for 2091-T3 0.144 Inch Sheet (Long Transverse Orientation)	367
K29 Tensile Results for 2091-T3 0.144 Inch Sheet Aged 16 Hours at 335°F (Longitudinal Orientation)	375
K30 Tensile Results for 2091-T3 0.144 Inch Sheet Aged 16 Hours at 335°F (45° Orientation)	375
K31 Tensile Results for 2091-T3 0.144 Inch Sheet Aged 16 Hours at 335°F (Long Transverse Orientation)	376
K32 Tensile Results for 2091-T3 0.144 Inch Sheet Aged 32 Hours at 335°F (Longitudinal Orientation)	376
K33 Tensile Results for 2091-T3 0.144 Inch Sheet Aged 32 Hours at 335°F (45° Orientation)	377
K34 Tensile Results for 2091-T3 0.144 Inch Sheet Aged 32 Hours at 335°F (Long Transverse Orientation)	377
K35 Kahn Tear Test Results for 2091-T3 0.144 Inch Sheet Aged 16 Hours at 335°F (L-T Orientation)	378
K36 Kahn Tear Test Results for 2091-T3 0.144 Inch Sheet Aged 16 Hours at 335°F (45° - 45° Orientation)	378

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
K37 Kahn tear Test Results for 2091-T3 0.144 Inch Sheet Aged 16 Hours at 335°F (T-L Orientation)	379
K38 Kahn Tear Test Results for 2091-T3 0.144 Inch Sheet Aged 32 Hours at 335°F (L-T Orientation)	379
K39 Kahn Tear Test Results for 2091-T3 0.144 Inch Sheet Aged 32 Hours at 335°F (45°-45° Orientation)	380
K40 Kahn Tear Test Results for 2091-T3 0.144 Inch Sheet Aged 32 Hours at 335°F (T-L Orientation)	380
K41 Tear-Yield Strength Ratios for 2091-T3 0.144 Inch Sheet Aged 16 Hours at 335°F	381
K42 Tear-Yield Strength Ratios for 2091-T3 0.144 Inch Sheet Aged 32 Hours at 335°F	381
K43 Tensile Results for 2091-T8 0.144 Inch Sheet, Longitudinal Orientation	383
K44 Tensile Results for 2091-T8 0.144 Inch Sheet, 45 Degree Orientation	383
K45 Tensile Results for 2091-T8 0.144 Inch Sheet, Long Transverse Orientation	384
K46 Compression Results for 2091-T8 0.144 Inch Sheet, Longitudinal Orientation	385
K47 Compression Results for 2091-T8 0.144 Inch Sheet, Long Transverse Orientation	385
K48 Slotted Shear Results for 2091-T8 0.144 Inch Sheet, Longitudinal Orientation	386
K49 Slotted Shear Results for 2091-T8 0.144 Inch Sheet, Long Transverse Orientation	386
K50 Bearing Results for 2091-T8 0.144 Inch Sheet, Longitudinal Orientation and $e/D=1.5$	387
K51 Bearing Results for 2091-T8 0.144 Inch Sheet, Long Transverse Orientation and $e/D=1.5$	387
K52 Bearing Results for 2091-T8 0.144 Inch Sheet, Longitudinal Orientation and $e/D=2.0$	388
K53 Bearing Results for 2091-T8 0.144 Inch Sheet, Long Transverse Orientation and $e/D=2.0$	388

<b>TABLE</b>		<b>PAGE</b>
<b>K54</b>	<b>R-Curve Fracture Toughness Results for 2091-T8X 0.144 Inch Sheet</b>	<b>389</b>
<b>L1</b>	<b>Tensile Results for 2091-T8 0.5 Inch Plate, Longitudinal Orientation</b>	<b>393</b>
<b>L2</b>	<b>Tensile Results for 2091-T8 0.5 Inch Plate, 30 Degree Orientation</b>	<b>393</b>
<b>L3</b>	<b>Tensile Results for 2091-T8 0.5 Inch Plate, 45 Degree Orientation</b>	<b>394</b>
<b>L4</b>	<b>Tensile Results for 2091-T8 0.5 Inch Plate, Long Transverse Orientation</b>	<b>394</b>
<b>L5</b>	<b>Compression Results for 2091-T8 0.5 Inch Plate, Longitudinal Orientation</b>	<b>395</b>
<b>L6</b>	<b>Compression Results for 2091-T8 0.5 Inch Plate, Long Transverse Orientation</b>	<b>395</b>
<b>L7</b>	<b>Fracture Toughness Results for 2091-T8 0.5 Inch Plate, L-T Orientation</b>	<b>396</b>
<b>L8</b>	<b>Fracture Toughness Results for 2091-T8 0.5 Inch Plate, T-L Orientation</b>	<b>396</b>
<b>L9</b>	<b>Post-Overload Fatigue Test Results for 2091-T8 0.5 Inch Plate and 2091-T83 0.144 Inch Plate</b>	<b>397</b>
<b>L10</b>	<b>Post-Overload Recovery Crack Extension in 2091 Plate and Sheet</b>	<b>401</b>
<b>M1</b>	<b>Tensile Results at t/2 Location for 8090-T8 Hat Extrusion (Longitudinal Orientation and Top Location)</b>	<b>407</b>
<b>M2</b>	<b>Tensile Results at t/2 Location for 8090-T8 Hat Extrusion (Longitudinal Orientation and Bottom Location)</b>	<b>407</b>
<b>M3</b>	<b>Tensile Results at t/2 Location for 8090-T8 Hat Extrusion (Longitudinal Orientation and Side Location)</b>	<b>408</b>
<b>M4</b>	<b>Bearing Results for 8090-T8 Hat Extrusion (Longitudinal Orientation, e/D=1.5 and Top Location)</b>	<b>409</b>
<b>M5</b>	<b>Bearing Results for 8090-T8 Hat Extrusion (Longitudinal Orientation, e/D=1.5 and Side Location)</b>	<b>409</b>
<b>M6</b>	<b>Bearing Results for 8090-T8 Hat Extrusion (Longitudinal Orientation, e/D=2.0 and Top Location)</b>	<b>410</b>

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
<b>M7</b> <b>Bearing Results for 8090-T8 Hat Extrusion (Longitudinal Orientation, <math>c/D=2.0</math> and Side Location)</b>	<b>410</b>
<b>M8</b> <b>Tensile Results at <math>t/2</math> Location for 8090-T8771 L-Extrusion, Longitudinal Orientation</b>	<b>411</b>
<b>M9</b> <b>Tensile Results at <math>t/2</math> Location for 8090-T8771 L-Extrusion, Long Transverse Orientation</b>	<b>412</b>
<b>M10</b> <b>Tensile Results at <math>t/2</math> Location for 8090-T8771 L-Extrusion, Short Transverse Orientation</b>	<b>413</b>
<b>M11</b> <b>Compression Results at <math>t/2</math> Location for 8090-T8771 L-Extrusion, Longitudinal Orientation</b>	<b>414</b>
<b>M12</b> <b>Compression Results at <math>t/2</math> Location for 8090-T8771 L-Extrusion, Long Transverse Orientation</b>	<b>415</b>
<b>M13</b> <b>Compression Results at <math>t/2</math> Location for 8090-T8771 L-Extrusion, Short Transverse Orientation</b>	<b>416</b>
<b>M14</b> <b>Rivet Shear Results for 8090-T8771 L-Extrusion, Longitudinal Orientation</b>	<b>417</b>
<b>M15</b> <b>Rivet Shear Results for 8090-T8771 L-Extrusion, Long Transverse Orientation</b>	<b>417</b>
<b>M16</b> <b>Fracture Toughness Results for 8090-T8771 L-Extrusion, L-T Orientation</b>	<b>418</b>
<b>M17</b> <b>Fracture Toughness Results for 8090-T8771 L-Extrusion, T-L Orientation</b>	<b>419</b>
<b>M18</b> <b>Fracture Toughness Results for 8090-T8771 L-Extrusion, S-L Orientation</b>	<b>420</b>
<b>M19</b> <b>Fracture Toughness Results for 8090-T8771 L-Extrusion, S-T Orientation</b>	<b>420</b>
<b>M20</b> <b>Fatigue Results with <math>R=0.1</math> and <math>K_t=1.0</math> for 8090-T8771 L-Extrusion, Longitudinal Orientation</b>	<b>421</b>
<b>N1</b> <b>Tensile Results at <math>t/2</math> Location for Kaiser 7064-T74511 Extrusion, Longitudinal Orientation</b>	<b>427</b>
<b>N2</b> <b>Tensile Results at <math>t/2</math> Location for Kaiser 7064-T74511 Extrusion, Long Transverse Orientation</b>	<b>427</b>
<b>N3</b> <b>Compression Results at <math>t/2</math> Location for Kaiser 7064-T74511 Extrusion, Longitudinal Orientation</b>	<b>428</b>

<b>TABLE</b>	<b>PAGE</b>
N4      Compression Results at t/2 location for Kaiser 7064-T74511 Extrusion, Long Transverse Orientation	428
N5      Iosipescu Shear results for Kaiser 7064-T74511 Extrusion, Longitudinal Orientation	429
N6      Iosipescu Shear Results for Kaiser 7064-T74511 Extrusion, Long Transverse Orientation	429
N7      Bearing Results for Kaiser 7064-T74511 Extrusion, Longitudinal Orientation and $e/D=1.5$	430
N8      Bearing Results for Kaiser 7064-T74511 Extrusion, Longitudinal Orientation and $e/D=2.0$	431
N9      Bearing Results for Kaiser 7064-T74511 Extrusion, Long Transverse Orientation and $e/D=2.0$	431
N10     Fracture Toughness Results for Kaiser 7064-T74511 Extrusion, L-T Orientation	432
N11     Fracture Toughness Results for Kaiser 7064-T74511 Extrusion, T-L Orientation	433
N12     Fatigue Results with $K_t=1.0$ and $R=0.1$ for Kaiser 7064-T74511 Extrusion, Longitudinal Orientation	434
N13     Fatigue Results with $K_t=3.0$ and $R=0.1$ for Kaiser 7064-T74511 Extrusion, Longitudinal Orientation	435
O1      Tensile Results at t/2 Location for Kaiser 7064-T74 Forging, Longitudinal Orientation	444
O2      Tensile Results at t/2 Location for Kaiser 7064-T74 Forging, Long Transverse Orientation	445
O3      Tensile Results at t/2 Location for Kaiser 7064-T74 Forging, Short Transverse Orientation	446
O4      Compression Results at t/2 Location for Kaiser 7064-T74 Forging, Longitudinal Orientation	447
O5      Compression Results at t/2 Location for Kaiser 7064-T74 Forging, Long Transverse Orientation	448
O6      Slotted Shear Results for Kaiser 7064-T74 Forging, Longitudinal Orientation	449
O7      Amsler Double Shear Results for Kaiser 7064-T74 Forging, L-T Orientation	449

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
O8      Iosipescu Shear Results for Kaiser 7064-T74 Forging, Longitudinal Orientation	450
O9      Iosipescu Shear Results for Kaiser 7064-T74 Forging, Long Transverse Orientation	450
O10     Bearing Results for Kaiser 7064-T74 Forging, Longitudinal Orientation and $c/D=1.5$	451
O11     Bearing Results for Kaiser 7064-T74 Forging, Long Transverse Orientation and $c/D=1.5$	451
O12     Bearing Results for Kaiser 7064-T74 Forging, Longitudinal Orientation and $c/D=2.0$	452
O13     Bearing Results for Kaiser 7064-T74 Forging, Long Transverse Orientation and $c/D=2.0$	452
O14     Fracture Toughness Results for Kaiser 7064-T74 Forging, L-T Orientation	453
O15     Fracture Toughness Results for Kaiser 7064-T74 Forging, T-L Orientation	454
O16     Fracture Toughness Results for Kaiser 7064-T74 Forging, S-T Orientation	455
O17     Fracture Toughness Results for Kaiser 7064-T74 Forging, S-L Orientation	456
O18     Fatigue Results for Kaiser 7064-T74 Forging (Longitudinal Orientation, $K_t=1.0$ and $R=0.1$ )	457
O19     Fatigue Results for Kaiser 7064-T74 Forging (Longitudinal Orientation, $K_t=3.0$ and $R=0.1$ )	458
O20     Fatigue Results for Kaiser 7064-T74 Forging (Longitudinal Orientation, $K_t=1.0$ and $R=-1.0$ )	460
P1      Tensile Results for Alcoa CW67 Sheet, Longitudinal Orientation	468
P2      Tensile Results for Alcoa CW67 Sheet, Long Transverse Orientation	468
P3      Compression Results for Alcoa CW67 Sheet, Longitudinal Orientation	469
P4      Compression Results for Alcoa CW67 Sheet, Long Transverse Orientation	469
P5      Slotted Shear Results for Alcoa CW67 Sheet, Longitudinal Orientation	470
P6      Bearing Results for Alcoa CW67 Sheet, Longitudinal Orientation and $c/D=1.5$	471

<b>TABLE</b>		<b>PAGE</b>
P7	Bearing Results for Alcoa CW67 Sheet, Long Transverse Orientation and $c/D=1.5$	471
P8	Bearing Results for Alcoa CW67 Sheet, Longitudinal Orientation and $c/D=2.0$	472
P9	Bearing Results for Alcoa CW67 Sheet Long Transverse Orientation and $c/D=2.0$	472
P10	R-Curve Data for Alcoa CW67 Sheet, Specimen 32 and L-T Orientation	473
P11	R-Curve Data for Alcoa CW67 sheet, Specimen 33 and L-T Orientation	474
P12	R-Curve Data for Alcoa CW67 Sheet Specimen 34 and T-L Orientation	475
P13	R-Curve Data for Alcoa CW67 Sheet, Specimen 35 and T-L Orientation	476
P14	R-Curve Data Associated with Figures P1 and P2 (Specimen 1)	478
P15	R-Curve Data Associated with Figures P1 and P2 (Specimen 2)	479
Q1	Tensile Results for Alcoa CW67 Plate, Longitudinal Orientation	485
Q2	Tensile Results for Alcoa CW67 Plate, Long Transverse Orientation	485
Q3	R-Curve Data Associated with Figures Q1 and Q2 (Specimen 1)	487
Q4	R-curve Data Associated with Figures Q1 and Q2 (Specimen 2)	488
R1	Tensile Results for Alcoa CW67 Extrusion, Longitudinal Orientation	490
R2	Tensile Results for Alcoa CW67 Extrusion, Long Transverse Orientation	490
R3	Compression Results for Alcoa CW67 Extrusion, Longitudinal Orientation	491
R4	Compression Results for Alcoa CW67 Extrusion, Long Transverse Orientation	491
R5	Iosipescu Shear Results for Alcoa CW67 Extrusion, Longitudinal Orientation	492

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
R6 Iosipescu Shear Results for Alcoa CW67 Extrusion, Long Transverse Orientation	492
R7 Amsler Double Shear Results for Alcoa CW67 Extrusion, L-S Orientation	493
R8 Bearing Results for Alcoa CW67 Extrusion, Longitudinal Orientation and $e/D=1.5$	494
R9 Bearing Results for Alcoa CW67 Extrusion, Long Transverse Orientation and $e/D=1.5$	495
R10 Bearing Results for Alcoa CW67 Extrusion, Longitudinal Orientation and $e/D=2.0$	495
R11 Bearing Results for Alcoa CW67 Extrusion, Long Transverse Orientation and $e/D=2.0$	495
R12 Fracture Toughness Results for Alcoa CW67 Extrusion, L-T Orientation	496
R13 Fracture Toughness Results for Alcoa CW67 Extrusion, T-L Orientation	496
R14 Fracture Toughness Results for Alcoa CW67 Extrusion, S-T Orientation	497
R15 Fracture Toughness Results for Alcoa CW67 Extrusion, S-L Orientation	497
S1 Tensile Results for Alcoa CW67 Forging, Longitudinal	520
S2 Tensile Results for Alcoa CW67 Forging, Long Transverse Orientation	520
S3 Tensile Results for Alcoa CW67 Forging, Short Transverse Orientation	521
S4 Compression Results for Alcoa CW67 Forging, Longitudinal Orientation	522
S5 Compression results for Alcoa CW67 Forging, Long Transverse Orientation	522
S6 Compression Results for Alcoa CW67 Forging, Short Transverse Orientation	523
S7 Pin Shear Results for Alcoa CW67 Forging, Longitudinal Orientation	524
S8 Pin Shear Results for Alcoa CW67 Forging, Long Transverse Orientation	524
S9 Bearing Results for Alcoa CW67 Forging	525

<b><u>TABLE</u></b>		<b><u>PAGE</u></b>
<b>S10</b>	<b>Fracture Toughness Results for Alcoa CW67 Forging, L-T Orientation</b>	<b>526</b>
<b>S11</b>	<b>Fracture Toughness Results for Alcoa CW67 Forging, L-S Orientation</b>	<b>526</b>
<b>S12</b>	<b>Fracture Toughness Results for Alcoa CW67 Forging, T-L Orientation</b>	<b>527</b>
<b>S13</b>	<b>Fracture Toughness Results for Alcoa CW67 Forging, T-S Orientation</b>	<b>527</b>
<b>S14</b>	<b>Fracture Toughness Results for Alcoa CW67 Forging, S-T Orientation</b>	<b>528</b>

## **PREFACE**

**This report was prepared by the Materials Engineering Branch (WL/MLSE), Systems Support Division, Materials Directorate, Wright Laboratory, Wright Patterson Air force Base, Ohio, under Project 2418, "Metallic Structural Materials, "Task 241807, "Systems Support, " Work Unit 24180703, Engineering and Design Data."**

**The authors would like to thank the participants who contributed to the program: U.S. Army, Boeing Commercial Airplane Co, General Dynamics Fort Worth Division, General Dynamics Space Systems Division, Grumman Aerospace, Lockheed, LTV Aerospace and Defense, Martin Marietta Manned Space Systems, McDonnell Douglas Space Systems, McDonnell Douglas Helicopters, McDonnell Douglas Missile Systems, McDonnell Aircraft, NASA Langley, Naval Air Development Center, Northrop, Sikorsky, Sundstrand Advanced Technical Group, Wyman-Gordon and the Air Force.**

## **SECTION 1**

### **INTRODUCTION**

**High performance aerospace systems are dependent on materials that are lighter, have improved mechanical properties, and/or offer a cost savings. Aluminum alloys that met these criteria were the newly developed aluminum-lithium alloys and the second generation powder metallurgy alloys.**

**In 1985, the Air Force along with the aerospace community found it important to investigate the potential of these promising aluminum alloys. A cooperative program was formed by the Wright Laboratory Materials Directorate, Systems Support Division, and a number of aerospace industries. The Air Force would obtain the test material from the producers, compile the test data, and submit reports to the participants. The participants agreed to support the program by performing mechanical property tests which include tension, compression, bearing, shear, fracture toughness, and fatigue related properties (S/N, da/dn). The Air Force elected to perform spectrum fatigue crack growth testing on most alloys. The following table contains the participants who volunteered to test a particular material. The X's that have a circle around them indicate the participants that submitted their data to the Air Force. Some participants were unable to test due to funding cuts or decrease in material interest.**

**This report contains aluminum-lithium alloys 2091, 8090, 2095, IN905XL and AL905XL, and powder metallurgy (P/M) aluminum alloys 7064 and CW67. Comparisons to other materials and ranking of materials are generally avoided, since each potential application may be based on different evaluation criteria.**

TABLE

Participants and Advanced Aluminum Alloys  
in the Cooperative Test Program

PARTICIPANTS	ALUMINUM LITHIUM ALLOYS										P/M ALUMINUM ALLOYS			
	PECHINEY 2091-T3 Sheet (0.063") 2091-T351 Plate (0.420") 2091-T6 Forging 8090-T651 T Extrusion	ALCAN 8090-T651 Extrusion 8090-T6771 Plate (1.75")	IncoMAP PM IN806XL Forging	ALCOA PM AL806XL Forging 2091-T3 Sheet (0.063") 2091-T3 Sheet (0.145") 2091-T6 Plate (0.50") 8090 Extrusion	REYNOLDS Weldable 649 R0315 Plate (0.8")	KAISER 7064-T74511 Extrusion 7064-T74 Forging CH67 Sheet (0.063") CH67 Plate (0.40") CH67 Extrusion CH67 Forging	ALCOA							
Air Force WPAFB, OH	⊙	⊙	⊙	⊙	⊙	⊙								
Army, MA					⊙	⊙								
AVCO, TN														
Boeing, WA	⊙	⊙	⊙	⊙										
Douglas Aircraft, CA					x	x	x	x	x					
General Dynamics, CA	⊙	⊙				⊙								
General Dynamics, TX	⊙	⊙	⊙	⊙			x	⊙	x	x				
Grumman Aerospace, NY	⊙	⊙		⊙	x									
Jet Propulsion, CA						x								
Lockheed, CA	x		x			x	x	x						
Lockheed, GA		⊙	x				x	x						
LTV, TX	⊙		⊙			⊙	x		x					
Martin Marietta, LA	⊙	⊙	⊙	x	⊙	⊙	⊙	⊙	⊙	⊙				
McDonnell Douglas Astro, CA						⊙								
McDonnell Douglas Helicopter, AR						⊙								
McDonnell Douglas Missile Sys, MO						⊙								
McDonnell Aircraft, MO	⊙					⊙	⊙	⊙			⊙			
NASA, VA			⊙			⊙	⊙							
Naval Air Development Center	⊙		⊙					x			x			
Northrop, CA	⊙	⊙	⊙		⊙	⊙	⊙	⊙	x	x				
Sikorsky, CT							x							
Sundstrand, IL						⊙								
Wyman-Gordon							x							

## SECTION 2

### MATERIALS AND TESTS

The advanced aluminum alloys were received on various dates. shown below are the aluminum alloys and approximate dates received.

Producer	Aluminum Alloy	Date Received
Alcan	8090-T651 Extrusion	Feb 86
	8090-T8771 Plate	May 91
Pechiney	2091-T3 Sheet	Jul 86
	2091-T351 Plate	Jul 86
	2091-T6 Forging	Jul 86
	8090-T651 Extrusion	Oct 86
Alcoa	2091-T3 Sheet (0.063")	Oct 88
	2091-T3 Sheet (o.144")	Mar 88
	2091-T8 Plate	Mar 89
	8090 Extrusion	Sep 91
INCO	IN905XL Forging	Jan 87
	AL905XL Forging	May 89
Reynolds	2095 Plate	Feb 91
Kaiser	7064 Extrusion	Dec 86
	7064 Forging	Dec 86
Alcoa	CW67 Sheet	Apr 89
	CW67 Plate	Apr 89
	CW67 Extrusion	Aug 87
	CW67 Forging	Oct 88

The aluminum-lithium alloys shown in the table above are shown in the as received condition. Some aerospace companies heat treated the alloys to T8 tempers.

Mechanical properties, (tension, compression, bearing, shear and fracture toughness) fatigue, and constant amplitude fatigue crack growth tests were tested according to ASTM standards, unless otherwise specified. Spectrum tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

## **SECTION 3**

### **PRESENTATION**

Each participant compiled a data package which contained the data they generated. Some of these data packages contained discussions and in other cases, only the data were provided. The tensile, compression, bearing, and shear data were put in tabular form. Fracture toughness, fatigue, fatigue crack growth, and spectrum fatigue crack growth data were put in tabular and graphical form.

## SECTION 4

### RESULTS AND DISCUSSION

The data generated by the participants are contained in the appendices. The following table lists the producer, aluminum alloy, form and the appendix that the data can be found.

Table  
Contents of Appendices

		Form	Appendix
Pechiney	2091	Plate	A
Pechiney	2091	Sheet	B
Pechiney	2091	Forging	C
Pechiney	8090	Extrusion	D
Alcan	8090	Extrusion	E
Alcan	8090	Plate	F
INCO	IN905XL	Forging	G
INCO	AL905XL	Forging	H
Reynolds	2095	Plate	I
Alcoa	2091	Sheet (0.063")	J
Alcoa	2091	Sheet (0.144")	K
Alcoa	2091	Plate	L
Alcoa	8090	Extrusion	M
Kaiser	7064	Extrusion	N
Kaiser	7064	Forging	O
Alcoa	CW67	Sheet	P
Alcoa	CW67	Plate	Q
Alcoa	CW67	Extrusion	R
Alcoa	CW67	Forging	S

## **SECTION 5**

### **CONCLUSIONS**

**Nineteen aerospace laboratories participated in generating data on the advanced aluminum alloys for the Air Force/Industry Cooperative Test Program Advanced Aluminum Alloys. The data contained in this report provides an extensive data base on the aluminum-lithium and P/M aluminum alloys.**

## **APPENDIX A**

### **PECHINEY 2091-T351 AND 2091-T8X PLATE (0.42" X 39" X 39")**

#### **INTRODUCTION**

The Pechiney 2091-T351 0.42-inch plates were received the second quarter of 1986. Three participants heat treated the plate to a T8X temper; Northrop - T8 condition was achieved by aging the 2091 plate at 275° for 12 hours, Grumman (-T8X) at 275°F for 12 hours, and General Dynamics TX (-T851) at 335° F for 16 hours.

#### **TESTING**

Basic mechanical properties (tension, compression, bearing, etc.) were tested according to ASTM standards, unless otherwise specified.

Constant amplitude fatigue crack growth tests were conducted according to ASTM E647 standard. The growth rate a-N data that was generated by the participants (Northrop, Grumman, General Dynamics CA, and Air Force) were reduced using a seven-point incremental polynomial method. This involves fitting a second-order polynomial (parabola) to sets of seven successive data points. The data are also checked against requirements per ASTM E647, Section 7.2. General Dynamics TX performed constant amplitude fatigue crack growth tests using a K-increasing (load increasing) method.

Spectrum tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

PECHINEY  
2091-T351 PLATE

**TABLE A1**  
**TENSILE RESULTS AT t/2 LOCATION FOR PECHINEY**  
**2091-T351 PLATE (0.42" X 39" X 39")**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
BOEING, WA	RT	LONG	64.5	51.3		17.0	
			64.5	51.2		16.0	
			64.6	51.4		17.0	
GENERAL DYNAMICS, CA	RT	LONG	64.3	51.3	10.2	20.2	10.8
			63.8	53.7	12.4	23.1	10.9
			63.9	51.0	12.5	25.8	10.9
			64.3	50.8	10.2	20.0	11.4
NADC	RT	LONG	68.2	55.5	15.0		11.2
			67.9	57.0	16.0		10.4
			68.2	55.2	15.0		11.7
			67.9	56.5	16.0		10.7
NORTHROP	RT	LONG	66.7	54.7	10.6	18.5	11.3
			67.3	55.2	11.0	18.1	11.3
			66.9	54.8	11.3	19.5	11.7
MARTIN MARIETTA, LA	RT	LONG	64.9	52.1	15.0	15.0	
			64.5	52.7	14.0	14.0	
			64.7	52.3	15.0	13.0	
AVERAGE			65.9	53.6	13.2	18.6	11.1
STANDARD DEVIATION			1.7	2.1	2.2	3.8	0.4

**TABLE A2**  
**TENSILE RESULTS AT t/2 LOCATION FOR PECHINEY**  
**2091-T351 PLATE (0.42" X 39" X 39")**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
-----							
BOEING, WA	RT	L TRANS	64.5	44.8		20.0	
			65.3	45.6		18.0	
			64.8	45.5		19.0	
GENERAL DYNAMICS, CA	RT	L TRANS	64.7	46.3	13.8	21.9	11.0
			64.4	46.5	13.4	24.4	11.1
			64.6	46.7	15.9	22.1	10.9
			65.2	47.2	14.2	22.2	11.2
NADC	RT	L TRANS	67.9	50.9	15.0		10.3
			66.2	49.9	16.0		11.7
			67.3	49.9	16.0		12.2
			66.2	49.9	15.0		10.7
NORTHROP	RT	L TRANS	67.2	49.1	12.1	23.4	11.7
			67.7	49.1	12.4	22.0	11.7
			67.6	49.0	12.8	24.8	12.3
MARTIN MARIETTA, LA	RT	L TRANS	65.8	46.6	16.0	15.0	
			65.4	46.0	20.0	17.0	
			65.2	46.6	18.0	15.0	
AVERAGE			65.9	47.6	15.0	20.4	11.3
STANDARD DEVIATION			1.2	1.9	2.2	3.3	0.6

TABLE A3  
COMPRESSION RESULTS AT t/2 LOCATION FOR PECHINEY  
2091-T351 PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
BOEING, WA	RT	LONG	42.7 42.8 42.6	
GENERAL DYNAMICS, CA	RT	LONG	42.0 41.7 41.6	11.4 11.6 11.7
NADC	RT	LONG	44.7 44.7 42.3 43.9 45.5 47.3 47.3	
MARTIN MARIETTA, LA	RT	LONG	44.5	12.4
AVERAGE			43.8	11.8
STANDARD DEVIATION			1.9	0.4

**TABLE A4**  
**COMPRESSION RESULTS AT t/2 LOCATION FOR PECHINEY**  
**2091-T351 PLATE (0.42" X 39" X 39")**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
BOEING, WA	RT	L TRANS	48.7 48.6 48.8	
GENERAL DYNAMICS, CA	RT	L TRANS	41.1 48.4 48.0	11.4 11.6 11.7
NADC	RT	L TRANS	50.9 49.9 49.4 47.2 52.8 47.7 51.7	
MARTIN MARIETTA, LA	RT	L TRANS	51.6	12.5
		AVERAGE	48.9	11.8
		STANDARD DEVIATION	2.8	0.5

**TABLE A5**  
**RIVET SHEAR RESULTS FOR PECHINEY**  
**2091-T351 PLATE (0.42" X 39" X 39")**

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
<hr/>		
GENERAL DYNAMICS, CA	LONG	34.3
		33.9
		33.4
	AVERAGE	33.9
	STANDARD DEVIATION	0.5

**TABLE A6**  
**RIVET SHEAR RESULTS FOR PECHINEY**  
**2091-T351 PLATE (0.42" X 39" X 39")**

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
<hr/>		
GENERAL DYNAMICS, CA	L TRANS	32.6
		36.6
		33.0
	AVERAGE	34.1
	STANDARD DEVIATION	2.2

**TABLE A7**  
**AMSLER DOUBLE SHEAR RESULTS FOR PECHINEY**  
**2091-T351 PLATE (0.42" X 39" X 39")**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<hr/>		
<b>BOEING, WA</b>	<b>L-S</b>	<b>35.2</b>
		<b>35.3</b>
		<b>35.2</b>
	<b>AVERAGE</b>	<b>35.2</b>
	<b>STANDARD DEVIATION</b>	<b>0.1</b>
<b>BOEING, WA</b>	<b>L-T</b>	<b>38.2</b>
		<b>38.0</b>
		<b>37.9</b>
	<b>AVERAGE</b>	<b>38.0</b>
	<b>STANDARD DEVIATION</b>	<b>0.2</b>
<b>BOEING, WA</b>	<b>T-S</b>	<b>34.4</b>
		<b>34.0</b>
		<b>34.5</b>
	<b>AVERAGE</b>	<b>34.3</b>
	<b>STANDARD DEVIATION</b>	<b>0.3</b>
<b>BOEING, WA</b>	<b>T-L</b>	<b>38.0</b>
		<b>38.0</b>
		<b>37.9</b>
	<b>AVERAGE</b>	<b>38.0</b>
	<b>STANDARD DEVIATION</b>	<b>0.1</b>

TABLE A8  
BEARING RESULTS FOR PECHINEY  
2091-T351 PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
BOEING. WA	LONG	1.5	88.0 87.0 90.0	66.4 * 67.2 67.2 *
GENERAL DYNAMICS. CA	LONG	1.5	90.8 89.4 89.4	81.6 72.0 70.5
		AVERAGE	89.1	70.8
		STANDARD DEVIATION	1.4	5.7

(\*): INDICATES SHEAR TEAR OUT FAILURE

TABLE A9  
BEARING RESULTS FOR PECHINEY  
2091-T351 PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
BOEING. WA	L TRANS	1.5	90.9 90.0 90.9	66.1 66.4 67.7
GENERAL DYNAMICS. CA	L TRANS	1.5	91.9 92.5 89.7	72.3 71.7 71.8
		AVERAGE	91.0	69.3
		STANDARD DEVIATION	1.1	2.9

**TABLE A10**  
**BEARING RESULTS FOR PECHINEY**  
**2091-T351 PLATE (0.42" X 39" X 39")**

COMPANY	ORIENTATION	e/D	BEARING	
			ULT. STR. (KSI)	YIELD STR. (KSI)
BOEING. WA	LONG	2.0	111.0	79.8
			111.8	81.0
			110.3	81.5
GENERAL DYNAMICS. CA	LONG	2.0	113.9	90.6
			115.8	85.8
			113.5	86.4
AVERAGE			112.7	84.2
STANDARD DEVIATION			2.1	4.1

**TABLE A11**  
**BEARING RESULTS FOR PECHINEY**  
**2091-T351 PLATE (0.42" X 39" X 39")**

COMPANY	ORIENTATION	e/D	BEARING	
			ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
BOEING. WA	L TRANS	2.0	114.8	82.3
			112.6	82.3
			115.2	83.2
GENERAL DYNAMICS. CA	L TRANS	2.0	113.0	87.6
			114.2	95.1
			114.6	87.4
AVERAGE			114.1	86.3
STANDARD DEVIATION			1.0	4.9

**TABLE A12**  
**FRACTURE TOUGHNESS RESULTS FOR PECHINEY**  
**2091-T351 PLATE (0.42" X 39" X 39")**

COMPANY	ORIENTATION	KIC	Kq	COMMENT
		(KSI in <sup>-0.5</sup> )	(KSI in <sup>-0.5</sup> )	
-----				
GENERAL DYNAMICS, CA	L-T		37.0	(1,2,3)
			34.5	(1,2,3)
			35.4	(1,2,3)
NADC	L-T		42.6	(1)
			42.6	(1)
			40.6	(1)
			36.6	(1)
AVERAGE			38.5	
STANDARD DEVIATION			3.4	

- (1): INVALID DUE TO  $P_{max}/P_q > 1.10$   
(2): INVALID DUE TO  $a < 2.5(KQ/Fty)^{-2}$   
(3): INVALID DUE TO  $B < 2.5(KQ/Fty)^{-2}$

**TABLE A13**  
**FRACTURE TOUGHNESS RESULTS FOR PECHINEY**  
**2091-T351 PLATE (0.42" X 39" X 39")**

COMPANY	ORIENTATION	KIC	Kq	COMMENT
		(KSI in <sup>-0.5</sup> )	(KSI in <sup>-0.5</sup> )	
-----				
GENERAL DYNAMICS, CA	T-L		38.7	(1,2,3)
			36.5	(1,2,3)
			33.0	(1,2,3)
	AVERAGE		36.1	
	STANDARD DEVIATION		2.9	

- (1): INVALID DUE TO  $P_{max}/P_Q > 1.10$   
(2): INVALID DUE TO  $a < 2.5(KQ/Fty)^{1/2}$   
(3): INVALID DUE TO  $B < 2.5(KQ/Fty)^{1/2}$

### R-CURVE FOR 2091 PLATE (longitudinal)

(effective crack length adjusted for plastic zone)

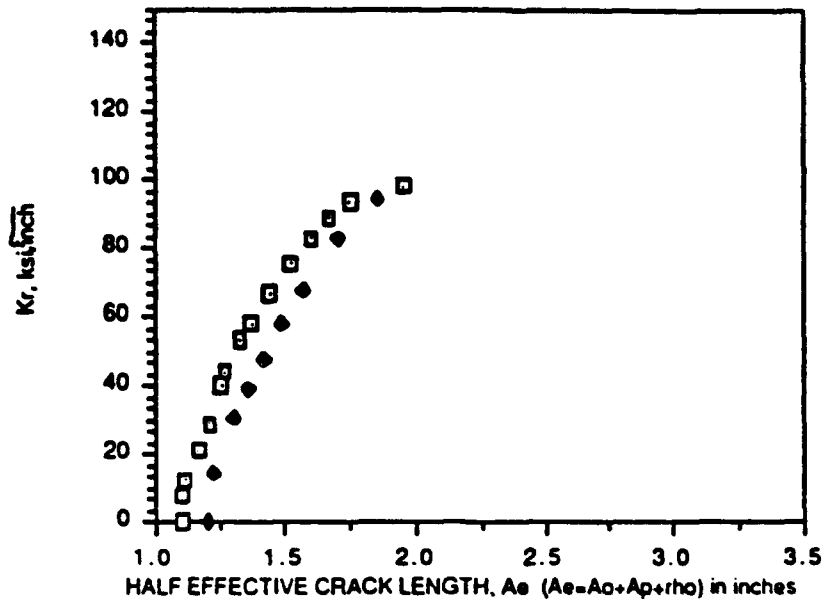


Figure A1 R-Curve Results for 2091-T351 0.42" Plate (longitudinal).  
Martin Marietta LA.

### R-CURVE FOR 2091 PLATE (transverse)

(effective crack length adjusted for plastic zone)

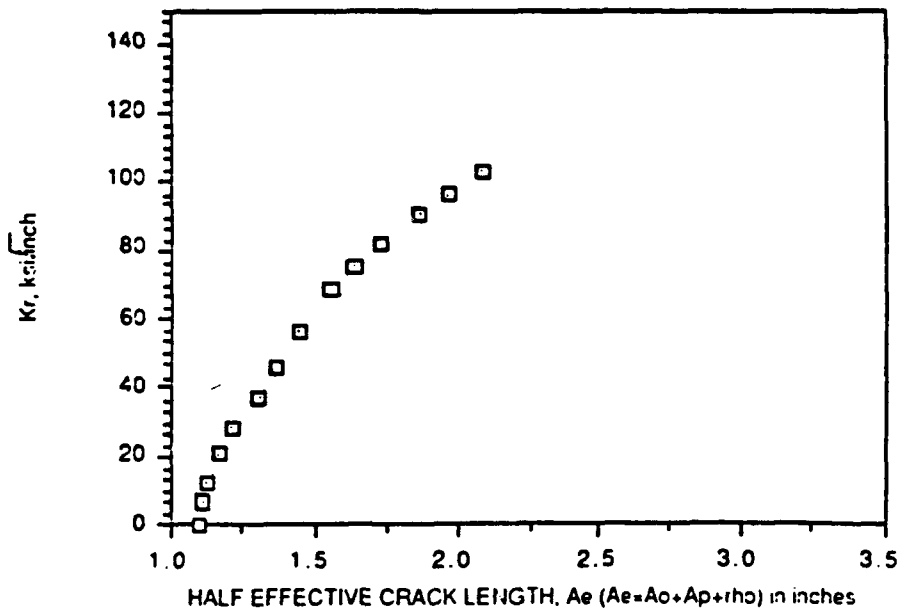


Figure A2 R-Curve Results for 2091-T351 0.42" Plate (transverse).  
Martin Marietta LA.

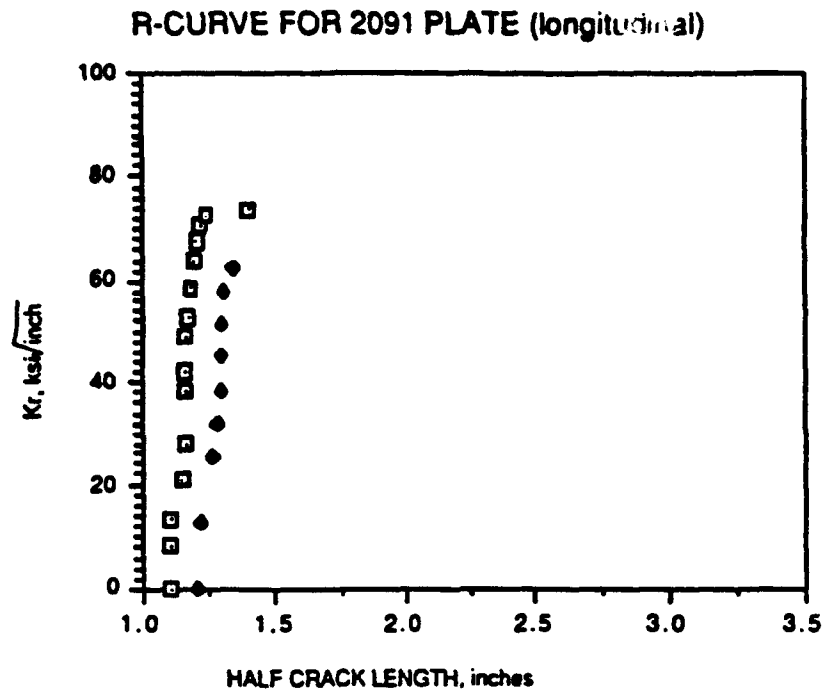


Figure A3 R-Curve Results for 2091-T351 0.42" Plate (longitudinal).  
Martin Marietta LA.

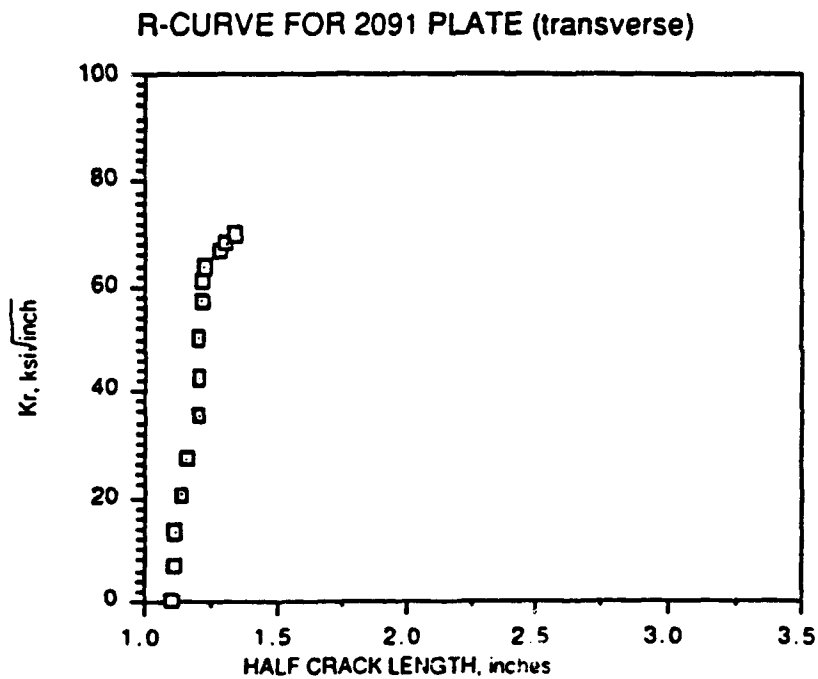


Figure A4 R-Curve Results for 2091-T351 0.42" Plate (transverse).  
Martin Marietta LA.

TABLE A14  
DATA FOR SPECIMEN NO. 1, 2091  
LONGITUDINAL PLATE

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi./inch	
			Not Adjusted	Adjusted for Plasticity
0.00	1.202	1.202	0.0	0.0
20.14	1.217	1.229	12.44	14.57
40.32	1.257	1.310	25.41	30.34
50.22	1.282	1.369	32.05	38.8
60.00	1.292	1.422	38.48	47.34
69.98	1.297	1.491	44.99	57.88
79.84	1.297	1.567	51.33	68.3
89.98	1.312	1.711	58.28	82.93
94.90	1.342	1.857	62.38	94.28

Thickness = .420 inch  
Yield = 52.4 ksi  
Specimen width = 7.00 inch

TABLE A15  
DATA FOR SPECIMEN NO. 2 2091  
LONGITUDINAL PLATE

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not Adjusted	Adjusted for Plasticity
0.0	1.100	1.100	0.0	0.0
12.54	1.100	1.104	8.45	7.93
20.3	1.100	1.110	13.68	12.84
30.09	1.145	1.171	20.80	21.06
40.17	1.165	1.213	28.08	28.71
54.79	1.165	1.257	38.30	39.89
60.16	1.165	1.278	42.06	44.16
69.79	1.165	1.329	46.79	53.14
75.44	1.175	1.375	53.03	58.74
83.47	1.180	1.440	58.84	66.95
90.09	1.190	1.522	63.86	75.72
95.15	1.200	1.600	67.82	82.82
98.00	1.215	1.673	70.43	86.90
99.15	1.245	1.750	72.43	93.30
93.49	1.400	1.958	74.14	96.06

Thickness = .420 inch  
Yield = 52.4 ksi  
Specimen Width = 7.00 inch

TABLE A16  
DATA FOR SPECIMEN NO. 3, 2091  
TRANSVERSE PLATE

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not Adjusted	Adjusted for Plasticity
0.0	1.100	1.100	0.0	0.0
9.93	1.110	1.113	6.73	6.31
19.81	1.115	1.127	13.46	12.61
20.65	1.135	1.167	20.38	20.69
39.73	1.160	1.220	27.70	28.46
49.74	1.205	1.307	35.50	37.13
59.86	1.210	1.364	42.90	45.68
69.86	1.210	1.444	50.06	56.26
79.58	1.215	1.561	57.39	68.41
85.32	1.215	1.639	61.32	75.71
88.14	1.230	1.728	63.87	82.05
91.82	1.280	1.872	66.62	90.59
91.79	1.305	1.973	68.35	96.81
90.86	1.340	2.090	69.83	103.00

Thickness = .420 inch  
Yield = 42.4 ksi  
Specimen width = 7.00 inch

TABLE A17  
FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR  
PECHINEY 2091-T351 PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
<hr/>			
NADC	LONG	60.0	28.300
		60.0	29.600
		50.0	72.400
		50.0	87.000
		45.0	395.500
		45.0	779.200
		40.0	1.47E+06
		40.0	2.00E+06
		35.0	1.11E+07
		32.5	1.00E+08 *

(\*): RUN OUT

# Pechiney 2091-T351 Plate (0.42" X 39" X 39")

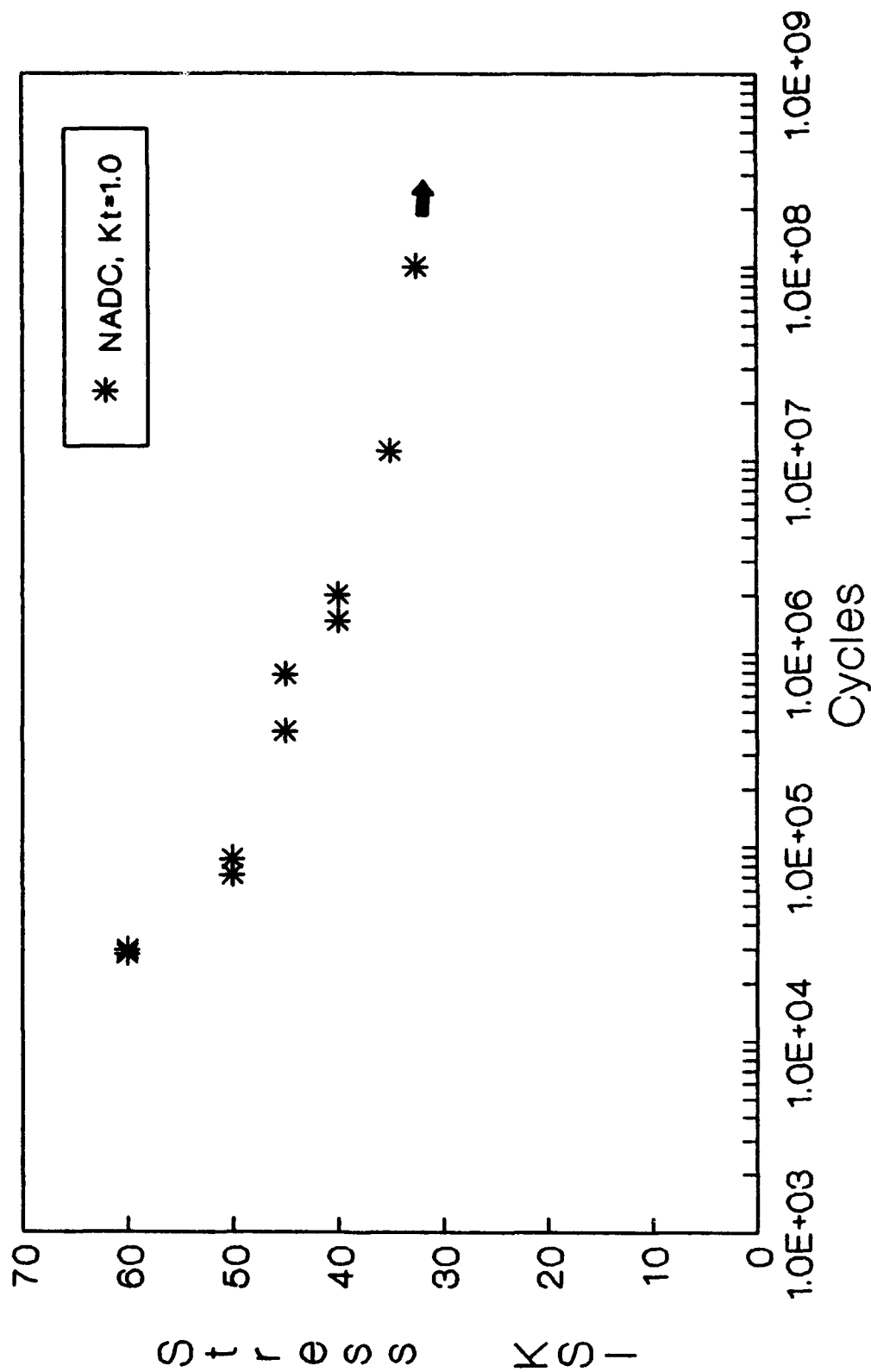


Figure A5 Fatigue Results for 2091-T351 0.42" Plate (R=0.1, Kt=1.0). NADC.

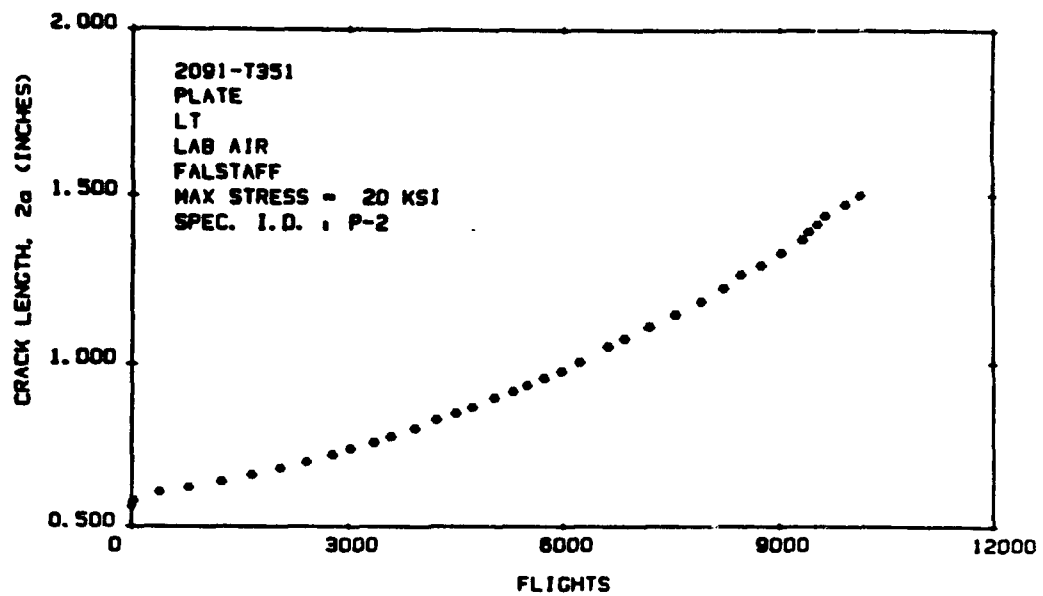


Figure A6 Crack Length Versus Flights for 2091-T351 Plate Under FALSTAFF Loading, Max Stress = 20 KSI.

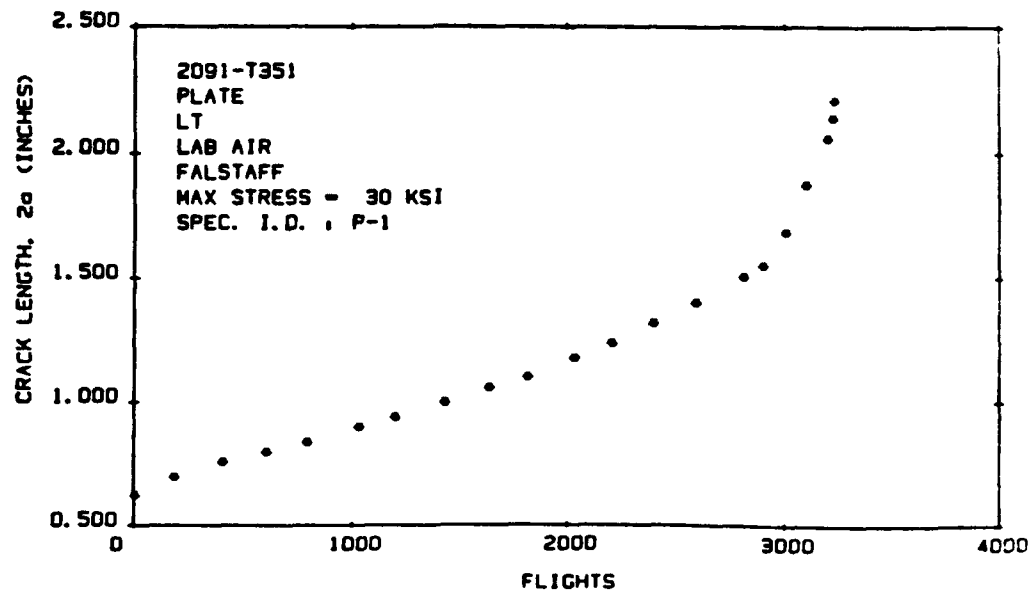


Figure A7 Crack Length Versus Flights for 2091-T351 Plate Under FALSTAFF Loading, Max Stress = 30 KSI.

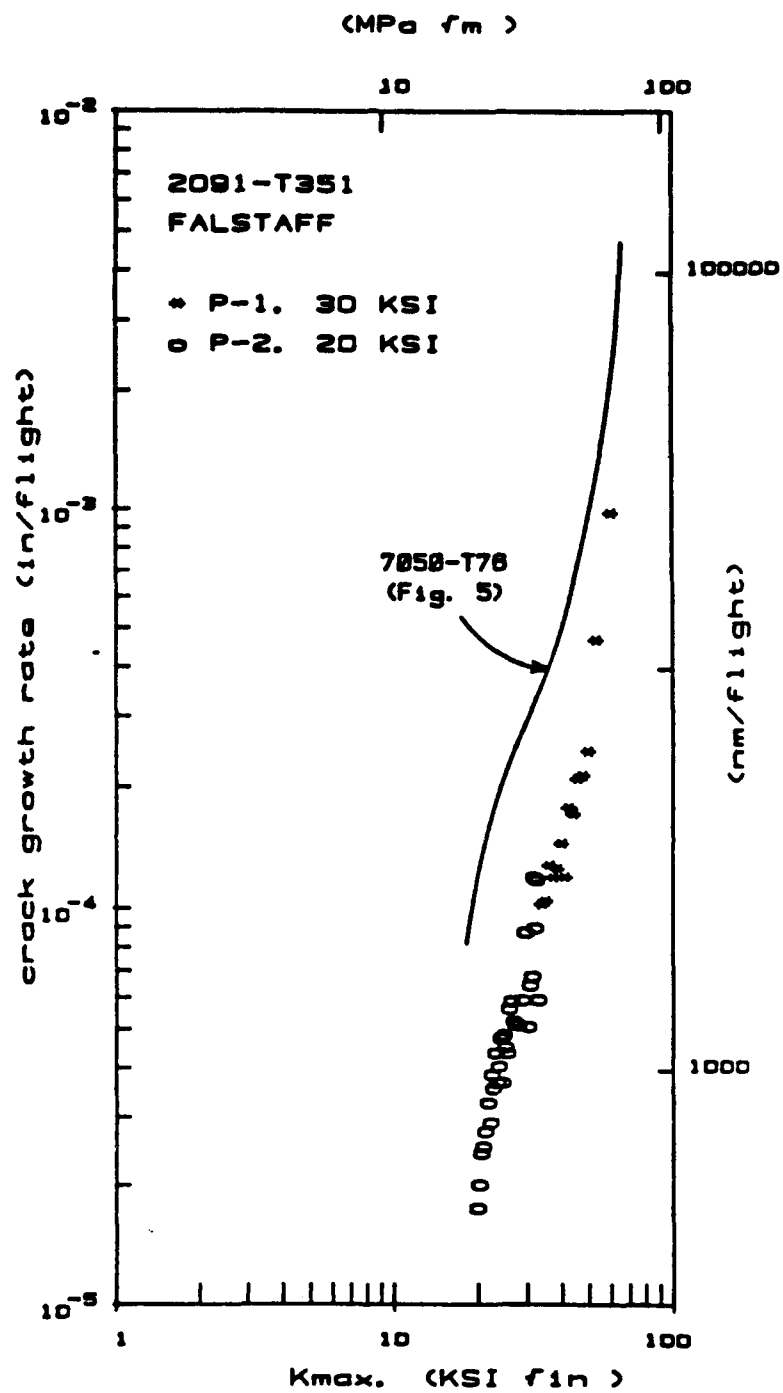


Figure A8 FALSTAFF Spectrum Results for 2091-T351 Reduced in Terms of Growth Rate and Maximum Spectrum Stress Intensity.

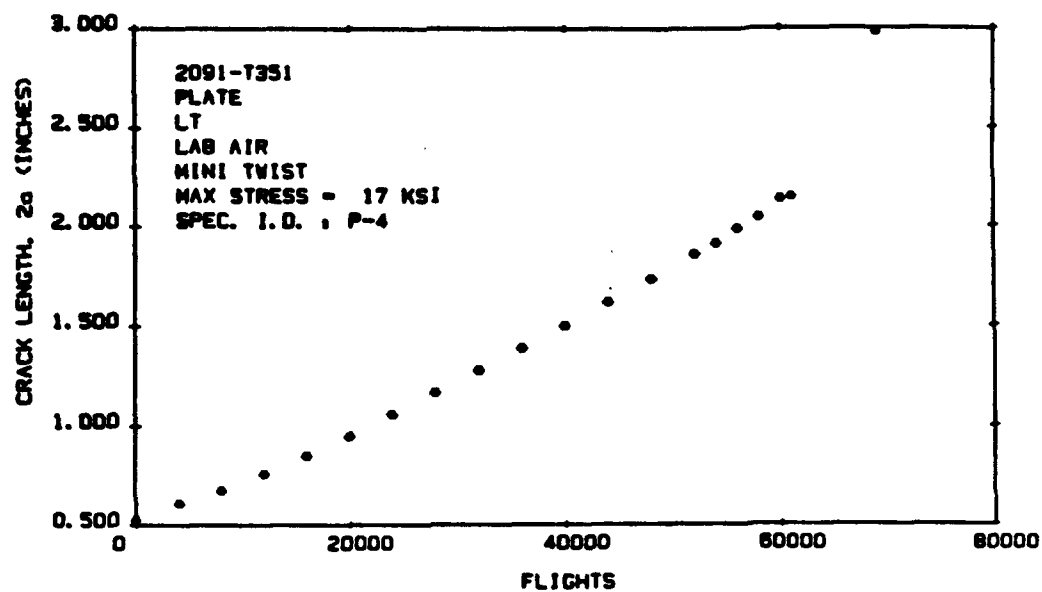


Figure A9 Crack Length Versus Flights for 2091-T351 Plate Under Mini-TWIST Loading, Max Stress = 17 KSI.

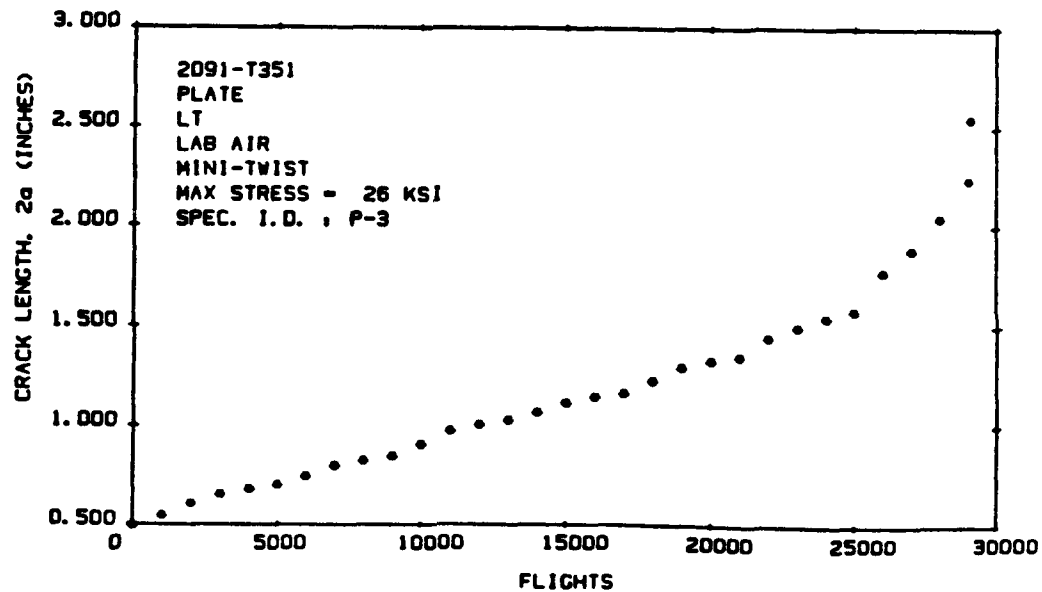
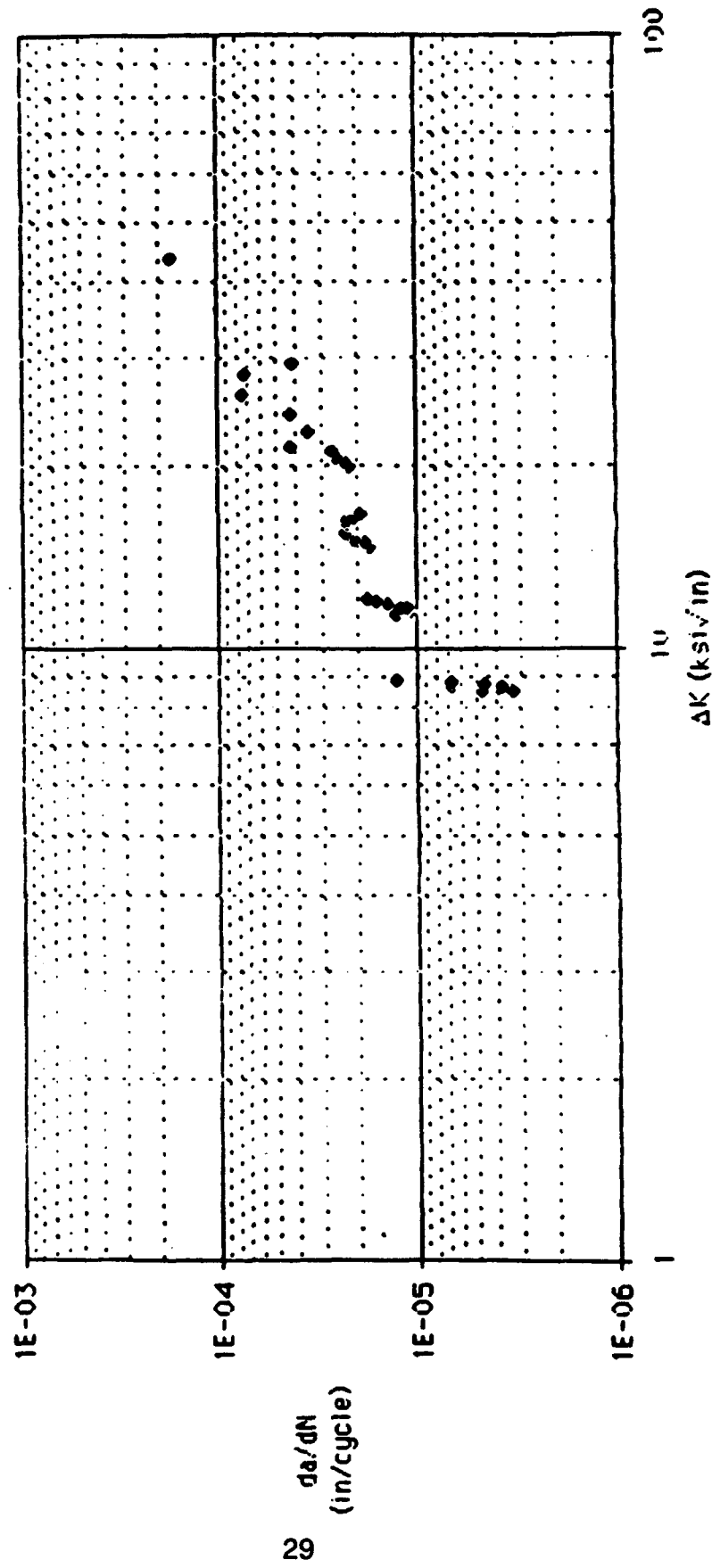


Figure A10 Crack Length Versus Flights for 2091-T351 Plate Under Mini-TWIST, Max Stress = 26 KSI.

ASTM E647 da/dN CHART C-6-LT-1



ASTM E647  $da/dN$  CHART C-6-TL-1

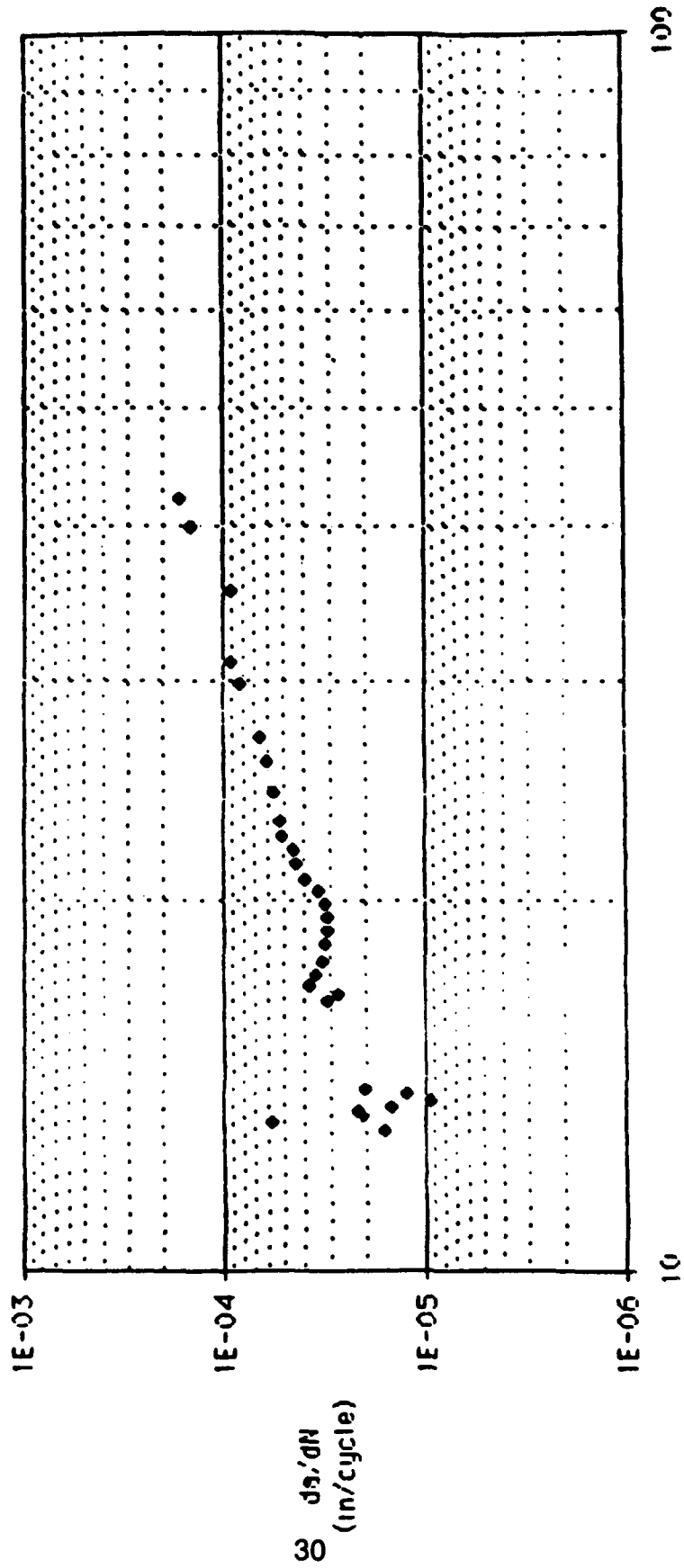


Figure A10b Fatigue Crack Growth Rate Data for 2091-T351 0.42" Plate (T-L Orientation). General Dynamics CA.

PECHINEY  
2091-T8X PLATE

TABLE A18  
TENSILE RESULTS AT t/2 LOCATION FOR PECHINEY  
2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	LONG	71.4	60.6	10.0	16.0	11.5
			71.5	59.9	12.0	16.0	11.4
			71.8	61.1	11.0	16.0	11.4
			71.5	60.4	10.0		11.4
			72.0	60.4	11.0		11.4
			72.0	60.6	9.0		11.5
GRUMMAN	RT	LONG	68.7	58.2	6.0	6.2	11.8
			70.0	58.2	8.5	9.2	11.9
			67.6	58.4	6.5	6.8	11.1
GENERAL DYNAMICS, TX	RT	LONG	72.8	60.6	8.0		
			72.5	60.8	7.3		
AVERAGE			71.1	59.9	9.0	11.7	11.5
STANDARD DEVIATION			1.6	1.1	2.0	4.8	0.2

TABLE A19  
TENSILE RESULTS AT t/2 LOCATION FOR PECHINEY  
2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	L TRANS	72.4	54.8	12.0	17.4	11.5
			72.5	55.0	12.0	17.8	11.6
			72.4	55.0	12.0	18.5	11.4
			69.2	51.1	15.0		11.4
			69.5	51.2	17.0		11.2
			69.1	50.9	16.0		11.8
GRUMMAN	RT	L TRANS	69.5	53.0	13.5	22.3	11.5
			69.0	51.1	13.0	16.8	13.0
			69.1	53.0	13.5	17.6	13.4
GENERAL DYNAMICS, TX	RT	L TRANS	71.8	55.9	11.0		
			72.0	55.9	11.0		
AVERAGE			70.6	53.4	13.3	18.4	11.9
STANDARD DEVIATION			1.6	2.0	2.0	2.0	0.8

TABLE A20

## TENSILE RESULTS AT t/2 LOCATION FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
GRUMMAN	RT	45	63.9	45.8	21.0	29.7	11.2
			62.5	45.7	21.5	27.2	11.1
			62.9	45.3	20.5	28.7	11.1
		AVERAGE	63.1	45.6	21.0	28.5	11.1
		STANDARD DEVIATION	0.7	0.3	0.3	1.3	0.1

TABLE A21

## TENSILE RESULTS AT t/10 LOCATION FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	LONG	71.6	60.0	10.0		11.3
			71.2	59.9	10.0		11.5
			71.4	60.4	10.0		11.1
		AVERAGE	71.4	60.1	10.0		11.3
		STANDARD DEVIATION	0.2	0.3	0.0		0.2

TABLE A22

## TENSILE RESULTS AT t/10 LOCATION FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	L TRANS	69.6	51.2	18.0		11.1
			69.3	51.1	16.0		11.6
			69.7	51.4	15.0		11.4
		AVERAGE	69.5	51.2	16.3		11.4
		STANDARD DEVIATION	0.2	0.2	1.5		0.3

TABLE A23

TENSILE RESULTS AT t/2 LOCATION WITH 100 HOURS EXPOSURE FOR  
PECHINEY 2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMP (DEGREES F)	EXPOSURE TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)
NORTHROP	RT	300	LONG	77.7	65.8	9.0	12.3
				77.7	65.9	9.0	11.6
		350	LONG	75.8	70.6	7.0	15.9
				76.1	70.7	7.0	18.9
		375	LONG	71.3	64.7	7.0	18.5
				71.6	64.8	7.0	18.1
		400	LONG	66.9	58.1	7.0	18.5
				66.7	58.0	7.0	18.1

**TABLE A24**  
**COMPRESSION RESULTS AT t/2 LOCATION FOR PECHINEY**  
**2091-T8X PLATE (0.42" X 39" X 39")**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
-----				
NORTHROP	RT	LONG	48.6	
			48.3	
			48.6	
GRUMMAN	RT	LONG	48.1	11.9
			50.5	11.5
			48.4	11.1
GENERAL DYNAMICS, TX	RT	LONG	48.6	
			49.2	
AVERAGE			48.8	11.5
STANDARD DEVIATION			0.8	0.4

TABLE A25

## COMPRESSION RESULTS AT t/2 LOCATION FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
NORTHROP	RT	L TRANS	57.6 57.4 57.5	
GRUMMAN	RT	L TRANS	58.3 58.2 58.9	11.9 11.2 11.6
GENERAL DYNAMICS. TX	RT	L TRANS	57.5 60.9	
AVERAGE			58.3	11.5
STANDARD DEVIATION			1.2	0.3

TABLE A26

## COMPRESSION RESULTS AT t/2 LOCATION FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
GRUMMAN	RT	45	49.5 48.6 49.6	11.3 11.4 10.8
AVERAGE			49.2	11.2
STANDARD DEVIATION			0.6	0.3

**TABLE A27**

**RIVET SHEAR RESULTS FOR PECHINEY  
2091-T8X PLATE (0.42" X 39" X 39")**

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
-----		
NORTHROP	L-S	35.9
		35.9
		35.9
GRUMMAN	L-S	36.4
		38.0
		37.8
AVERAGE		36.6
STANDARD DEVIATION		1.0

**TABLE A28**

**RIVET SHEAR RESULTS FOR PECHINEY  
2091-T8X PLATE (0.42" X 39" X 39")**

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
-----		
NORTHROP	T-S	33.5
		33.5
		33.9
GRUMMAN	T-S	34.6
		35.9
		37.2
AVERAGE		34.8
STANDARD DEVIATION		1.5

TABLE A29

SLOTTED SHEAR RESULTS FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
<hr/>		
GENERAL	LONG	41.3
DYNAMICS, TX		40.9
	AVERAGE	41.1
	STANDARD DEVIATION	0.3

TABLE A30

SLOTTED SHEAR RESULTS FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
<hr/>		
GENERAL	L TRANS	42.6
DYNAMICS, TX		43.4
	AVERAGE	43.0
	STANDARD DEVIATION	0.6

TABLE A31  
BEARING RESULTS FOR PECHINEY  
2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
NORTHROP	LONG	1.5		93.0		73.0
				89.6		71.8
				92.6		73.7
GRUMMAN	LONG	1.5		92.9		71.9
				93.8		73.0
				93.4		72.1
GENERAL DYNAMICS, TX	LONG	1.5		117.0		93.0
				112.0		91.4
AVERAGE				98.0		77.5
STANDARD DEVIATION				10.3		9.1

**TABLE A32**  
**BEARING RESULTS FOR PECHINEY**  
**2091-T8X PLATE (0.42" X 39" X 39")**

COMPANY	ORIENTATION	e/D	BEARING	
			ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
NORTHROP	L TRANS	1.5	99.3	75.5
			98.9	76.0
			97.9	74.2
GRUMMAN	L TRANS	1.5	94.9	73.0
			91.9	70.1
			92.8	71.0
GENERAL DYNAMICS. TX	L TRANS	1.5	97.0	79.1
			97.8	80.5
AVERAGE			96.3	74.9
STANDARD DEVIATION			2.8	3.6

TABLE A33

BEARING RESULTS FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	e/D	BEARING		BEARING
			ULT.	STR.	YIELD STR.
			(KSI)		(KSI)
NORTHROP	LONG	2.0	119.4	86.8	
			118.9	87.8	
			118.6	86.4	
GRUMMAN	LONG	2.0	113.0	85.6	
			115.5	86.9	
			114.2	87.1	
GENERAL DYNAMICS, TX	LONG	2.0	123.0	91.3	
			122.0	94.0	
AVERAGE			118.1	88.2	
STANDARD DEVIATION			3.6	2.9	

TABLE A34

BEARING RESULTS FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
NORTHROP	L TRANS	2.0		123.9		90.7
				124.2		94.2
				124.1		92.1
GRUMMAN	L TRANS	2.0		115.6		88.2
				117.5		89.5
				114.9		88.9
GENERAL DYNAMICS, TX	L TRANS	2.0		99.3		82.7
				103.0		85.3
AVERAGE				115.3		89.0
STANDARD DEVIATION				9.6		3.7

**TABLE A35**  
**FRACTURE TOUGHNESS RESULTS FOR PECHINEY**  
**2091-T8X PLATE (0.42" X 39" X 39")**

COMPANY	ORIENTATION	KIC	Kq	COMMENT
		(KSI in <sup>-0.5</sup> )	(KSI in <sup>-0.5</sup> )	
NORTHROP	L-T	27.0		VALID
		28.0		VALID
GRUMMAN	L-T		40.1	INVALID(1)
			43.2	INVALID(1,2)
			39.5	INVALID(1,2)
GENERAL DYNAMICS, TX	L-T		29.9	INVALID(2,3,4)
			29.0	INVALID(2,3,4)
	AVERAGE	27.5	36.3	
	STANDARD DEVIATION	0.7	6.5	

- (1):  $2.5(Kq)^2 / (YS)^2 > B$   
(2):  $P_{max}/P_q > 1.10$   
(3): INSUFFICIENT THICKNESS  
(4): CRACK CURVATURE > 5%

**TABLE A36**  
**FRACTURE TOUGHNESS RESULTS FOR PECHINEY**  
**2091-T8X PLATE (0.42" X 39" X 39")**

COMPANY	ORIENTATION	KIC	Kq	COMMENT
		(KSI in <sup>-0.5</sup> )	(KSI in <sup>-0.5</sup> )	
-----				
NORTHROP	T-L	29.8		VALID
		28.5		VALID
GRUMMAN	T-L		40.5	INVALID(1)
			43.2	INVALID(1,2)
			38.2	INVALID(1,2)
GENERAL DYNAMICS, TX	T-L		27.1	INVALID(2,3)
			27.0	INVALID(2,3,4)
	AVERAGE	29.2	35.2	
	STANDARD DEVIATION	0.9	7.6	

- (1):  $2.5(Kq)^2 / (YS)^2 > B$   
(2):  $P_{max}/P_q > 1.10$   
(3): INSUFFICIENT THICKNESS  
(4): CRACK CURVATURE > 5%

TABLE A37

General Dynamics, Texas  
 Pechiney 2091-T8X Plate  
 (0.42" X 39" X 39")  
 Results of R-Curve Tests

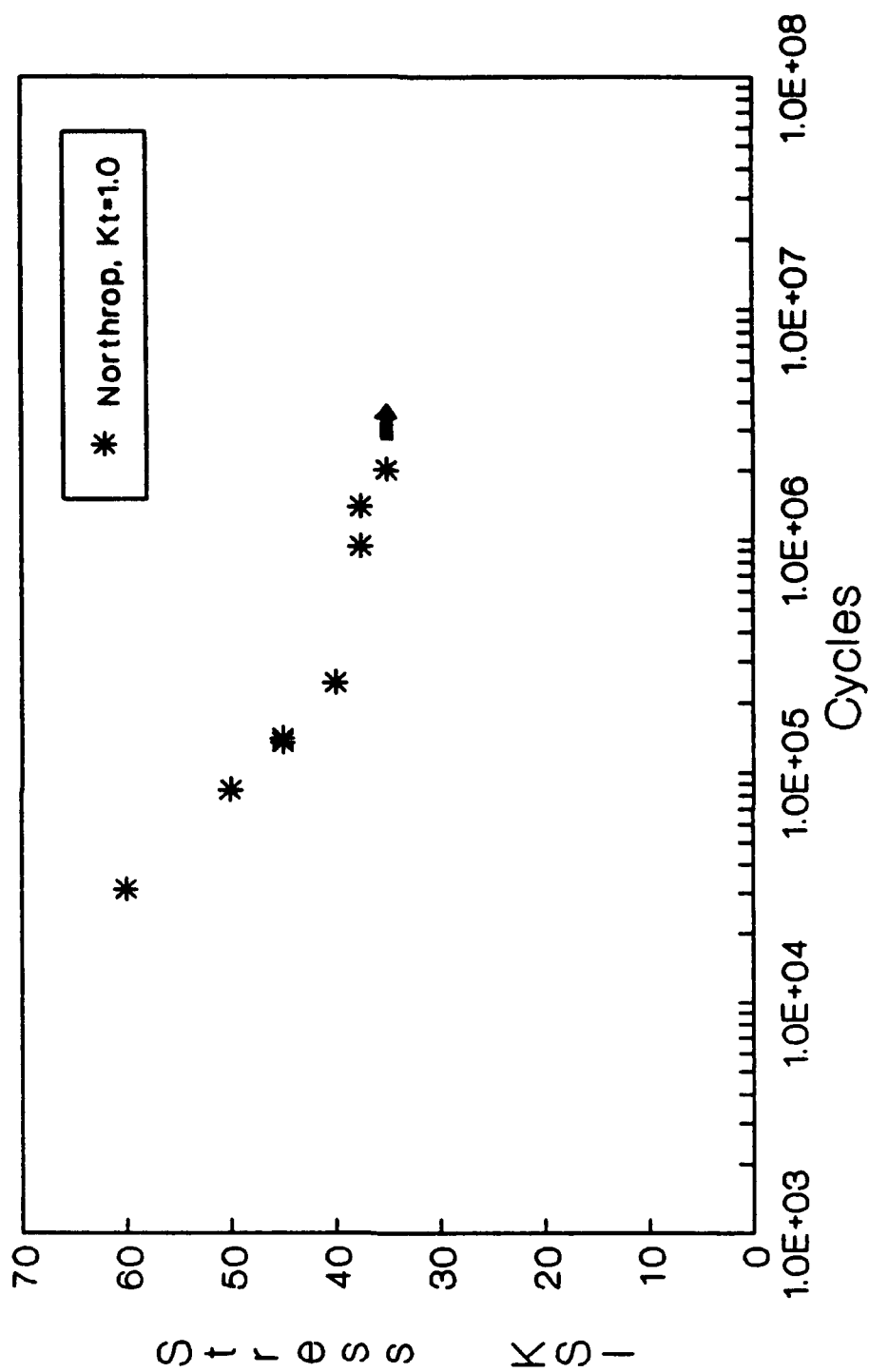
	$K_{R25}, \text{ksi-in}^{\frac{1}{2}}$
L-T	48.3
L-T	50.2
T-L	43.2
T-L	43.2

TABLE A38  
SMOOTH FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR  
PECHINEY 2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
<hr/>			
NORTHROP	LONG	60.0	31,299
		50.0	84,556
		45.0	135,397
		45.0	140,237
		40.0	242,930
		37.5	1,386,890
		37.5	934,697
		35.0	2,000,000 *

(\*): INDICATES RUN-OUT TEST

Pechiney 2091-T8X Plate  
(0.42" X 39" X 39")



**Figure A11 Fatigue Results for 2091-T8X 0.42" Plate (R=0.1, Kt=1.0). Northrop.**

**TABLE A39**  
**NOTCHED FATIGUE RESULTS WITH R=0.1 AND Kt=3.0 FOR**  
**PECHINEY 2091-T8X PLATE (0.42" X 39" X 39")**

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
<hr/>			
NORTHROP	LONG	45.0	13,635
		40.0	26,179
		35.0	48,930
		30.0	216,536
		27.5	257,234
		27.5	193,418
		25.0	474,737 *
		23.0	940,075

(\*): INDICATES SLANT FAILURE

# Pechiney 2091-T8X Plate (0.42" X 39" X 39")

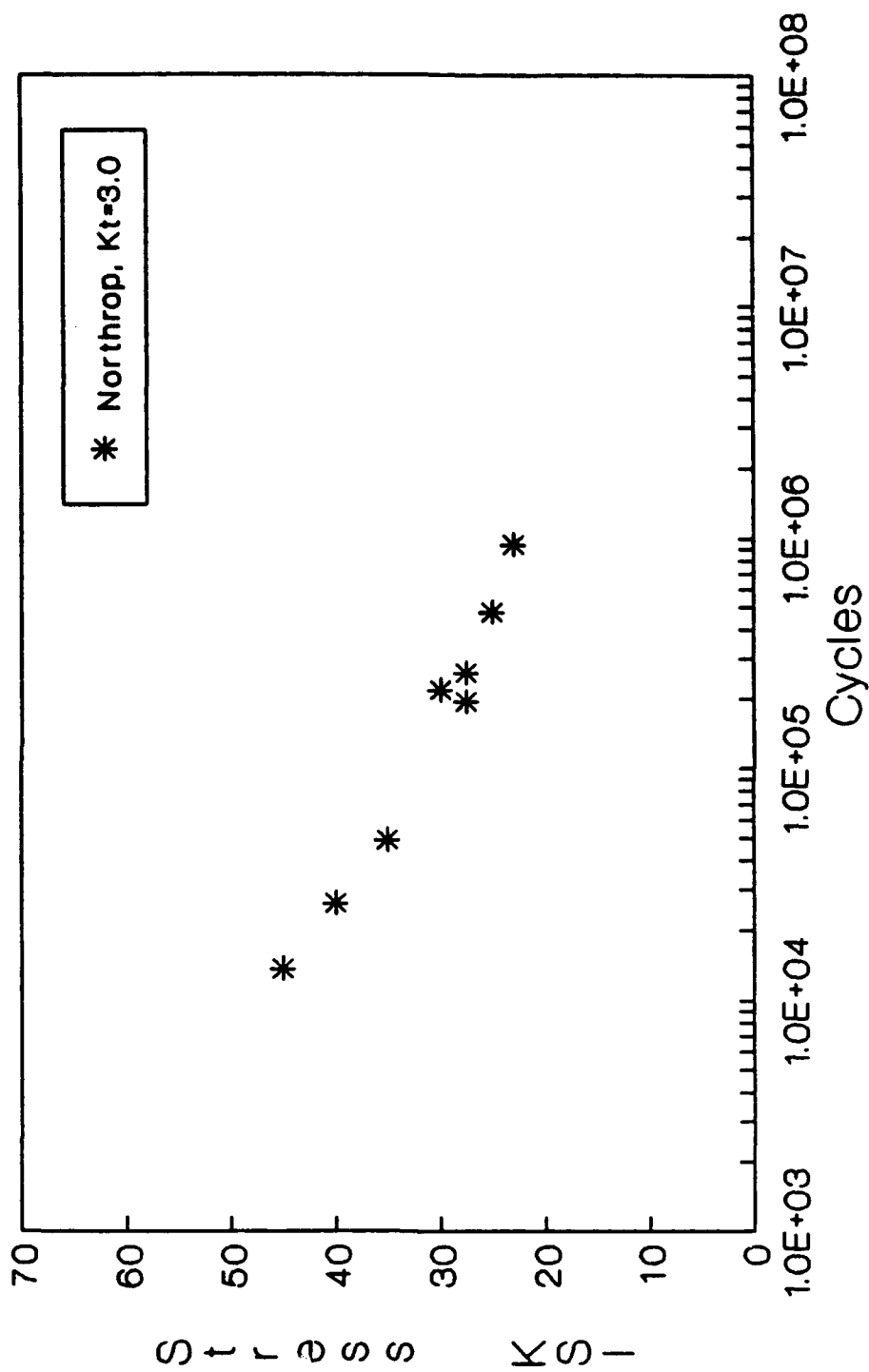


Figure A12 Fatigue Results for 2091-T8X 0.42" Plate (R=0.1, Kt=3.0). Northrop.

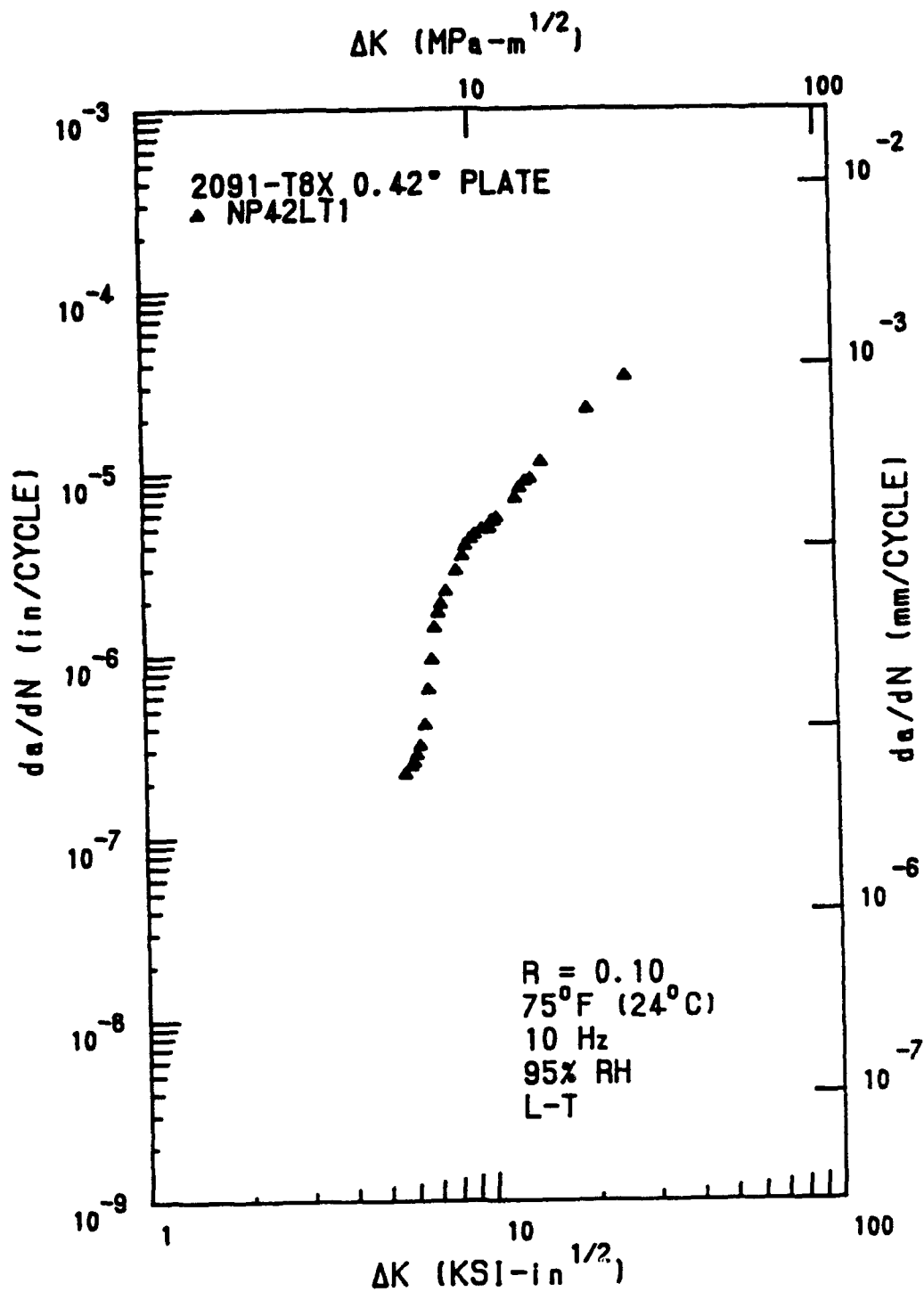


Figure A13 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.42" Plate (L-T Orientation). Northrop.

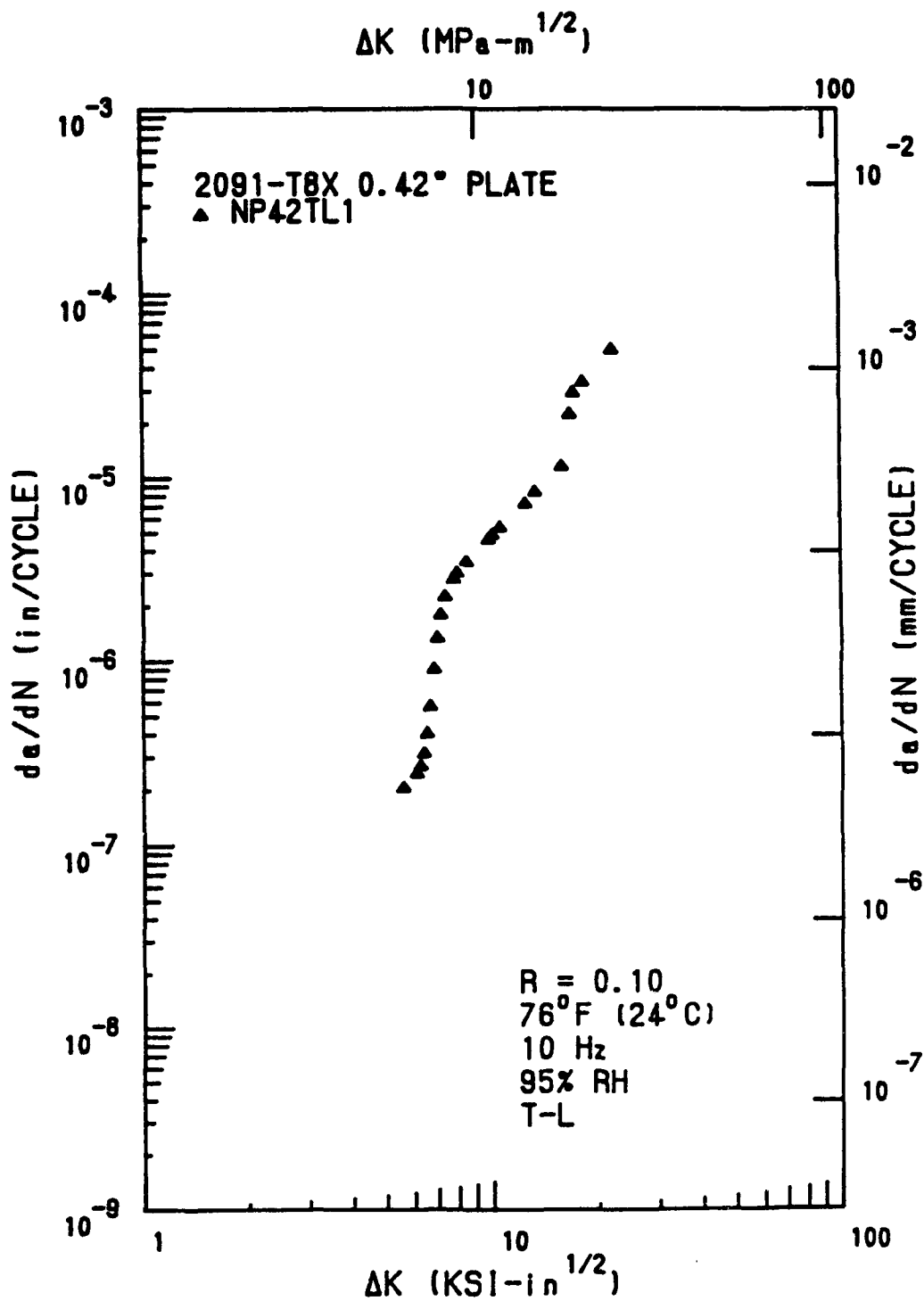


Figure A14 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.42" Plate (T-L Orientation). Northrop.

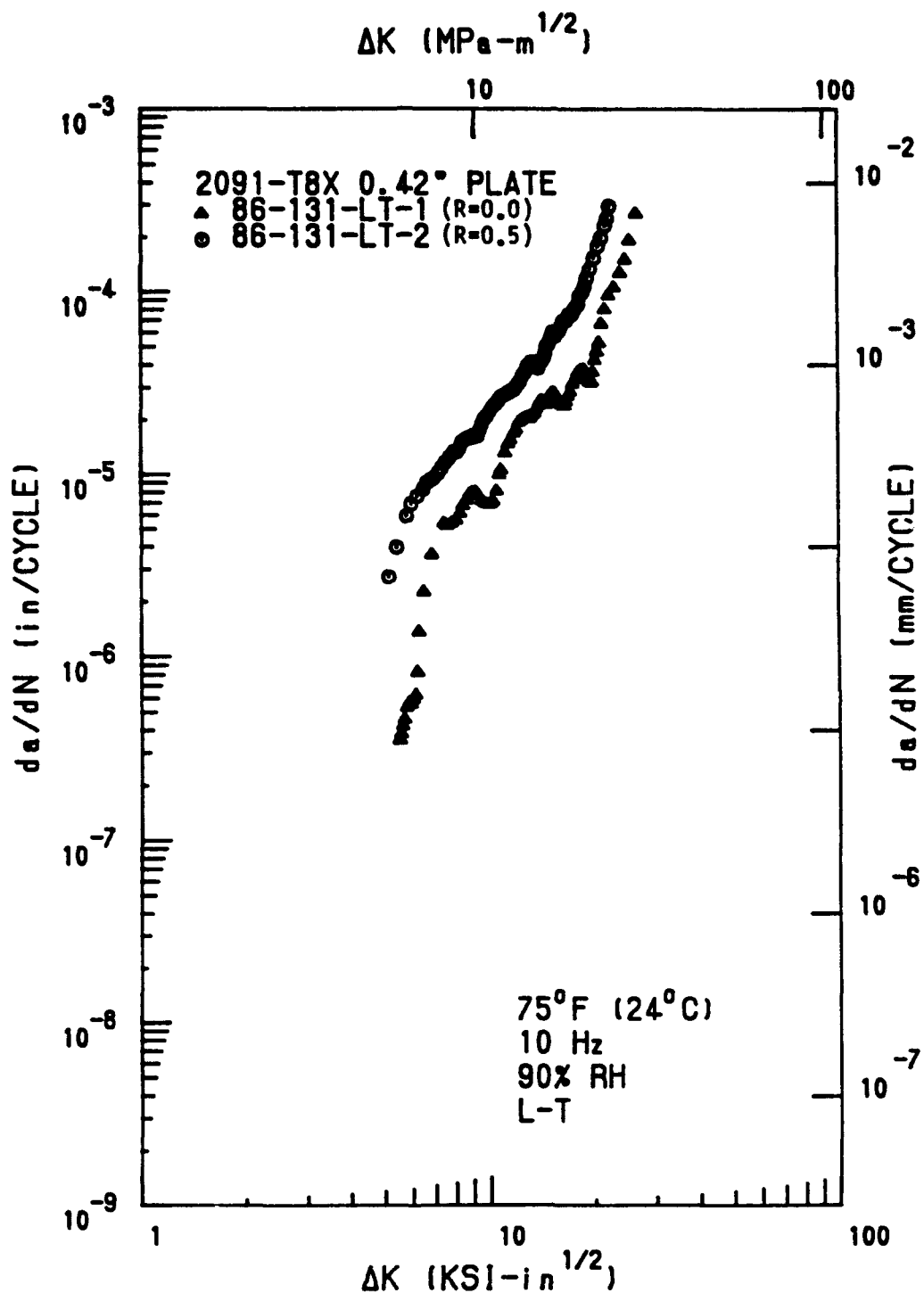


Figure A15 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.42" Plate (L-T Orientation). Grumman.

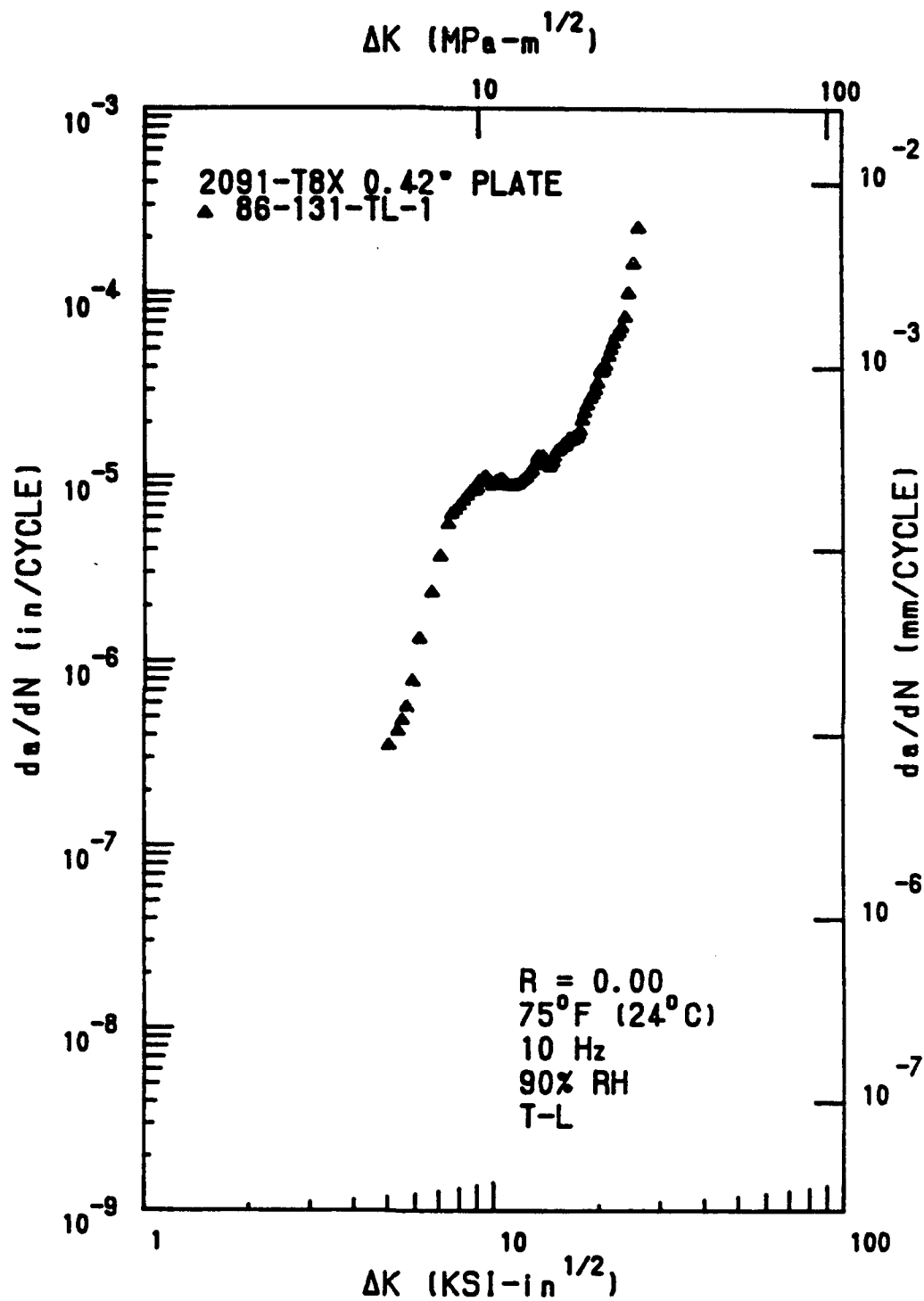


Figure A16 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.42" Plate (T-L Orientation). Grumman.

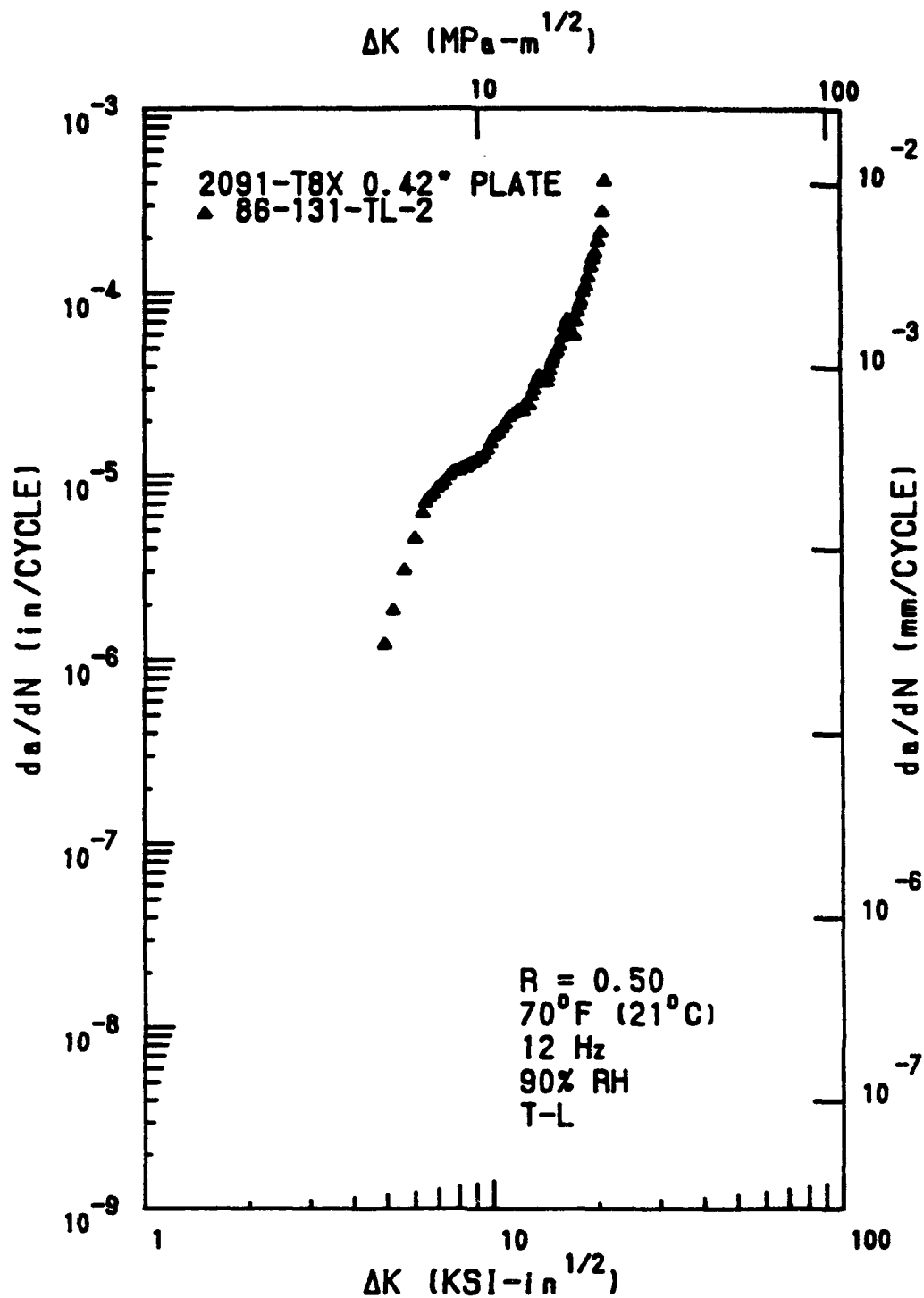


Figure A17 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.42" Plate (T-L Orientation). Grumman.

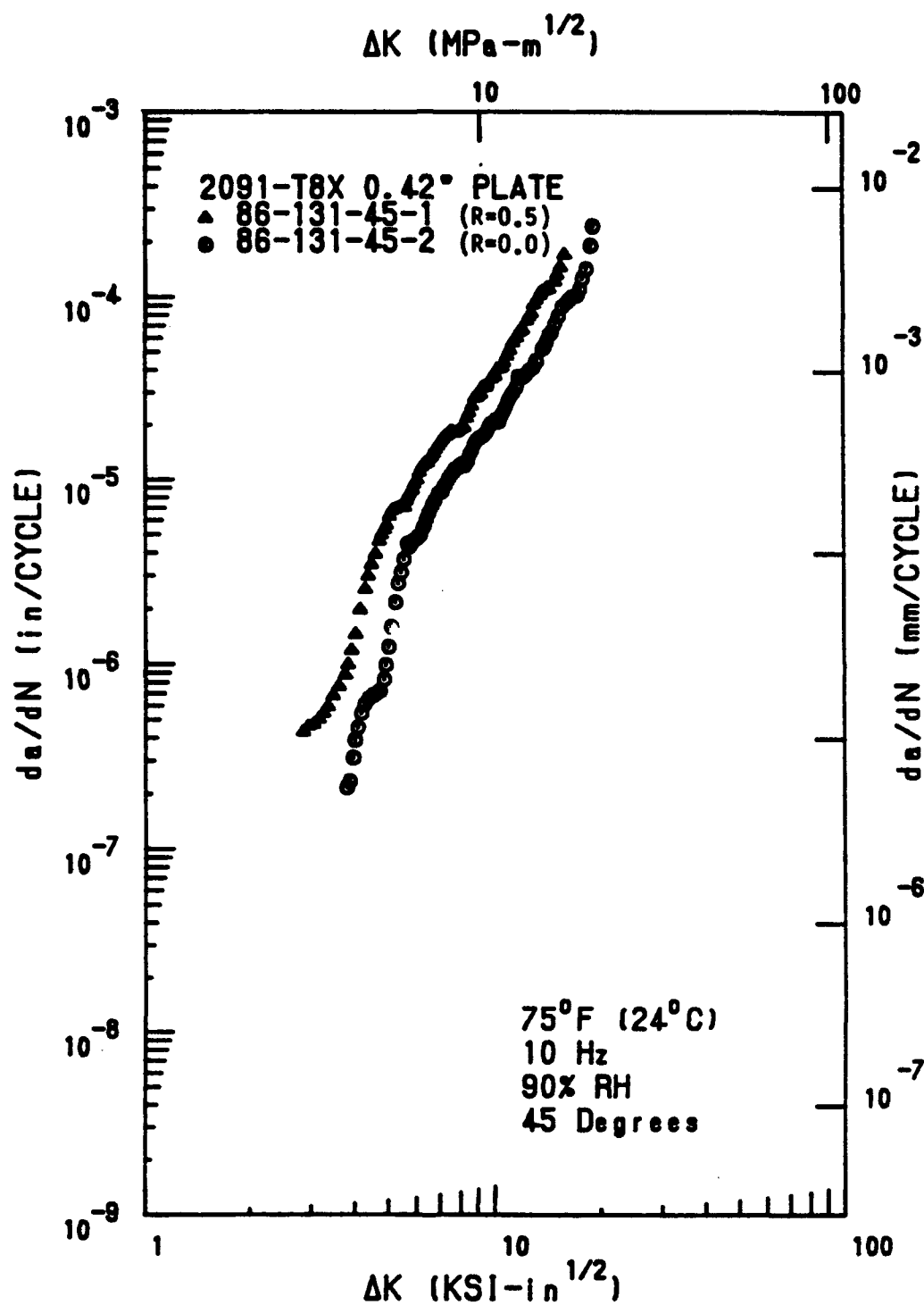
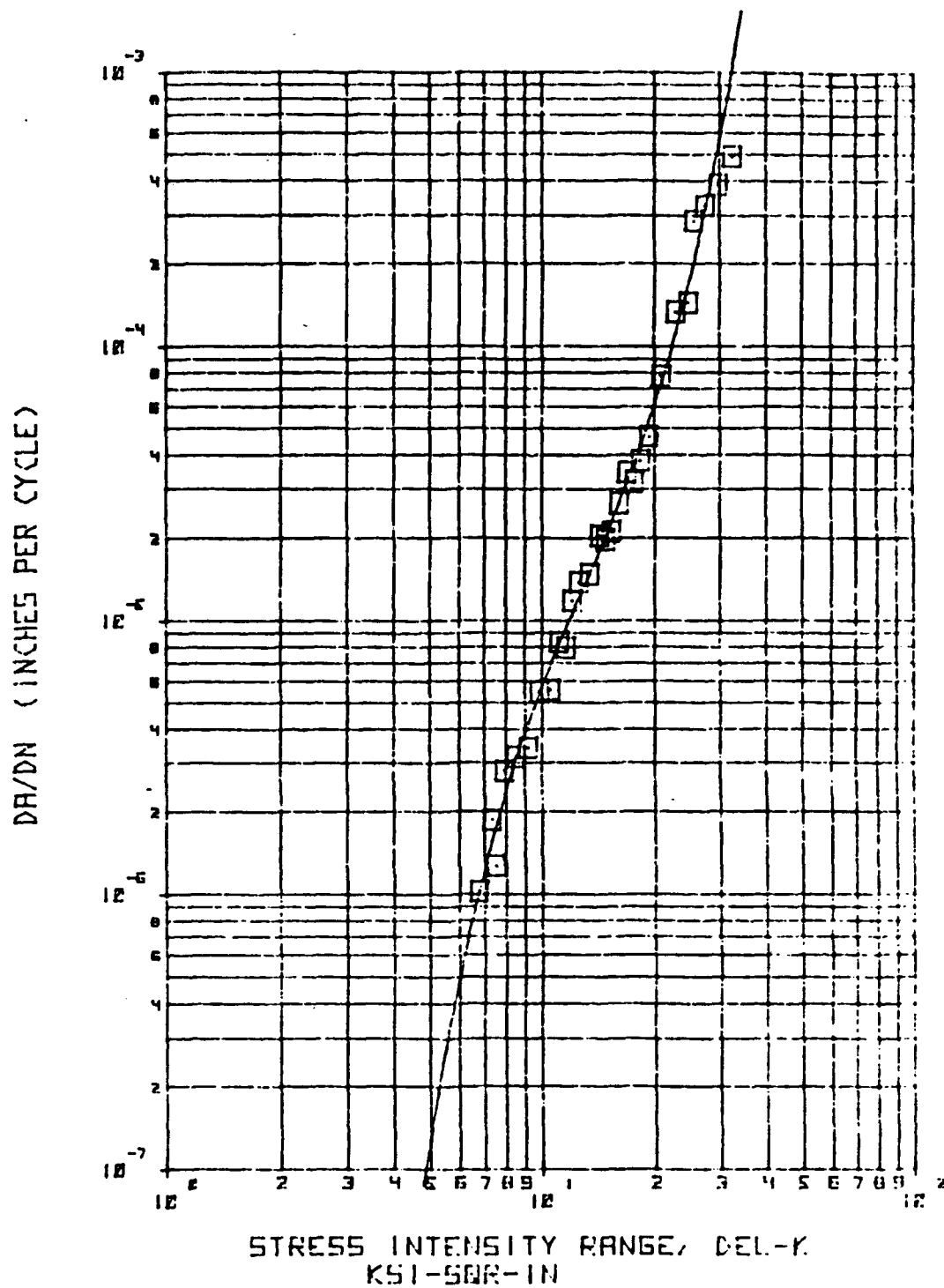
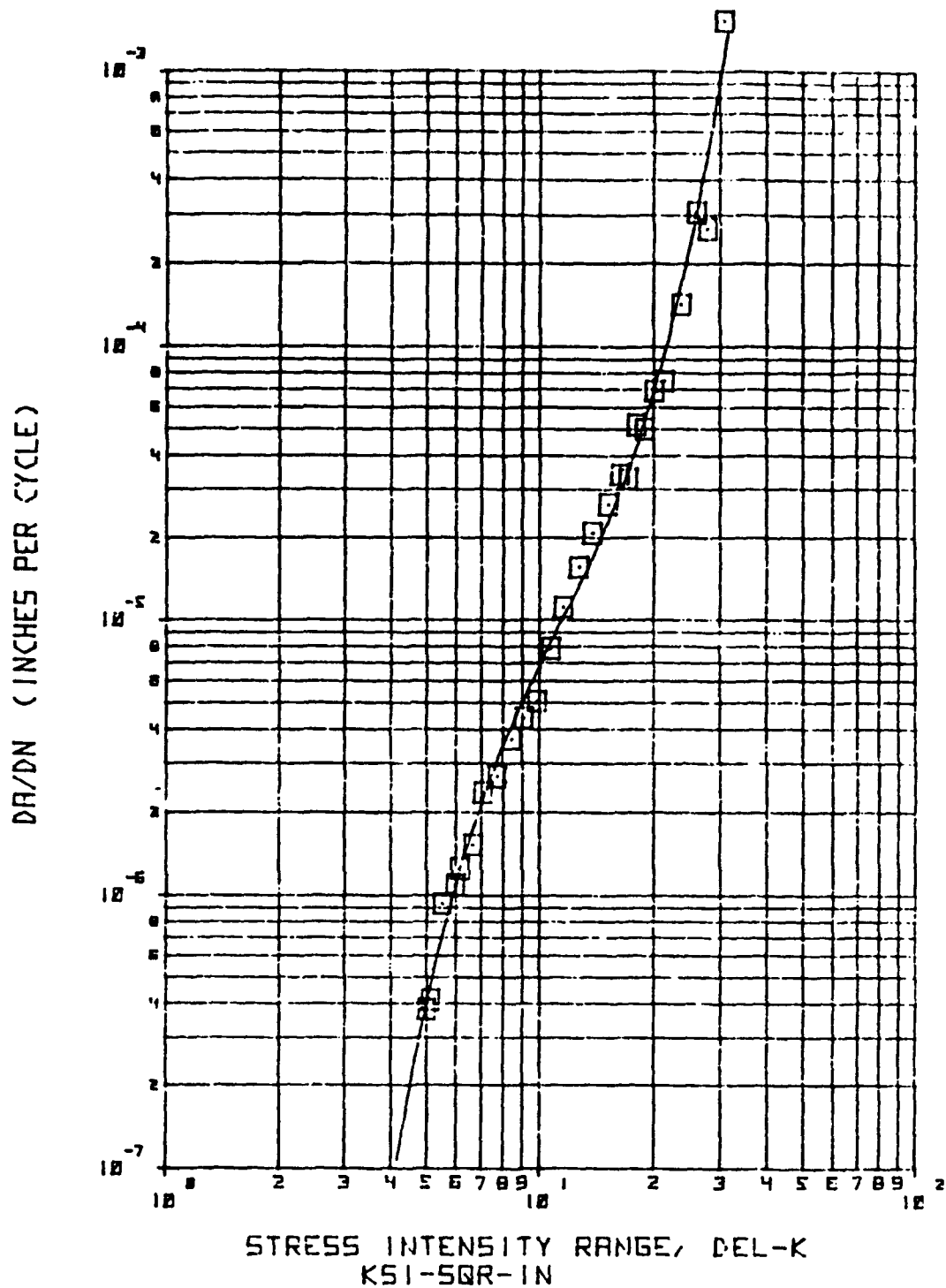


Figure A18 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.42" Plate (45 degrees Orientation). Grumman.



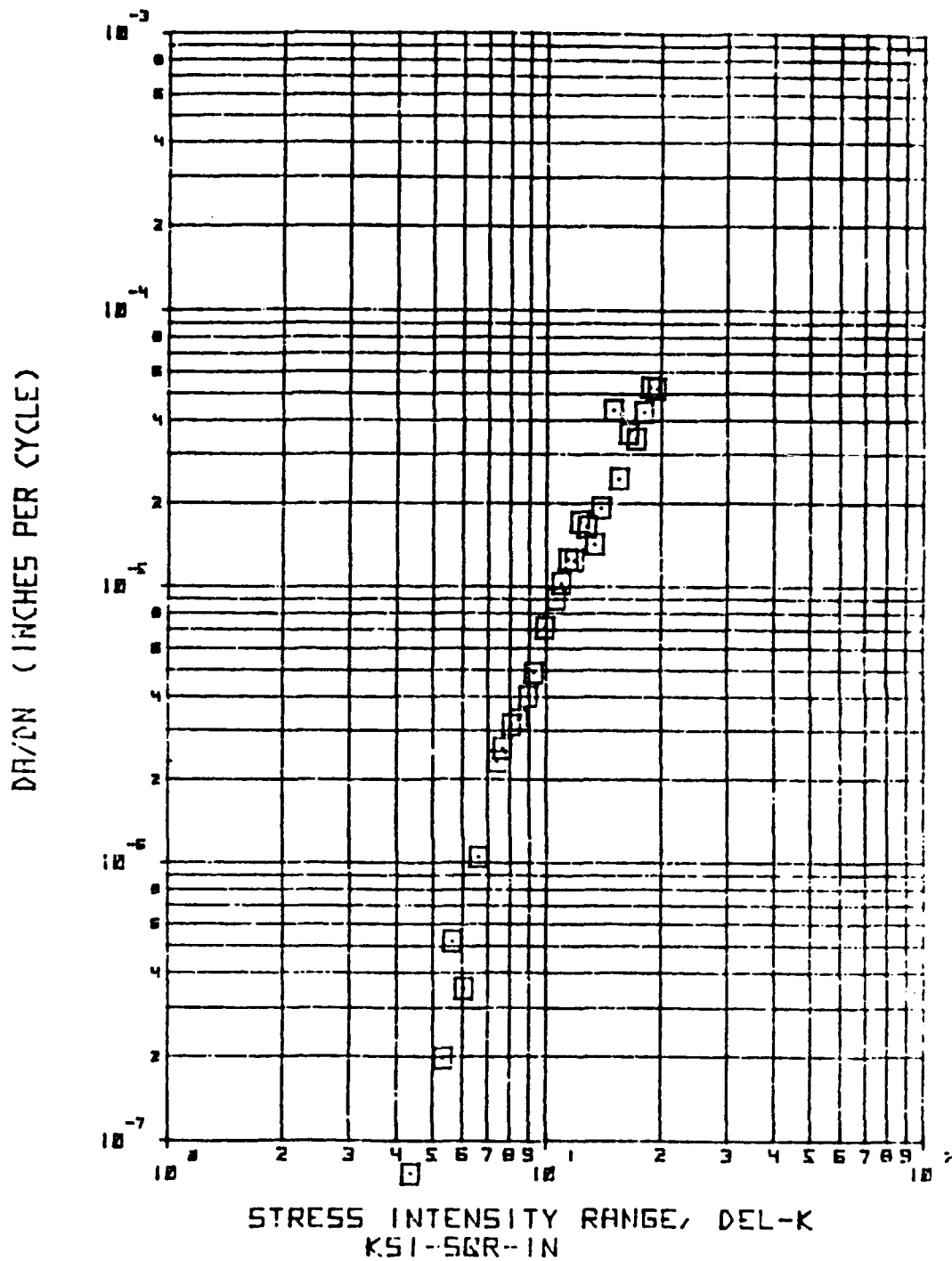
Material: 2091-T851 Plate  
 Age: 335°F - 16 hrs  
 Environment: Lab air, Room temperature  
 Orientation: L-T  
 Stress Ratio: 0.1  
 Frequency: 5 Hz

Figure A19 Fatigue Crack Growth Rate Data for 2091-T8X 0.42" Plate (L-T orientation). General Dynamics TX.



Material: 2091-T851 Plate  
 Age: 335°F - 16 hrs  
 Environment: Lab air, Room temperature  
 Orientation: T-L  
 Stress Ratio: 0.1  
 Frequency: 5 Hz

Figure A20 Fatigue Crack Growth Rate Data for 2091-T8X 0.42" Plate (T-L orientation). General Dynamics TX.



Material: 2091-T851 Plate  
 Age: 335°F - 16 hrs  
 Environment: Lab air, Room temperature  
 Orientation: T-L  
 Stress Ratio: 0.1  
 Frequency: 5 Hz

Figure A21 Fatigue Crack Growth Rate Data for 2091-T8X 0.42" Plate (T-L orientation). General Dynamics TX.

## **APPENDIX B**

### **PECHINEY 2091-T3 AND 2091-T8X (0.063" X 79" X 39')**

#### **INTRODUCTION**

The Pechiney 2091-T3 0.063-inch sheets were received the second quarter of 1986. Three participants heat treated the 2091-T3 to a T8X temper. Grumman Aircraft Systems and Northrop Corporation achieved the T8 condition by aging the 2091 sheet at 275°F for 12 hours (recommended by the producer of this alloy). General Dynamics Fort Worth Division aged the 2091 sheet at 335°F for 32 hours achieving the T81 condition.

#### **TESTING**

Basic mechanical properties (tension, compression, bearing, etc.) were tested according to ASTM standards, unless otherwise specified.

Constant amplitude fatigue crack growth tests were conducted according to ASTM E647 standard. The growth rate  $a-N$  data that was generated by the participants (Grumman, McDonnell Aircraft Co., and Northrop) were reduced using a seven-point incremental polynomial method. This involves fitting a second-order polynomial (parabola) to sets of seven successive data points. The data are also checked against size requirements per ASTM E647, Section 7.2. General Dynamics, TX performed constant amplitude fatigue crack growth tests using a K-increasing (load increasing) method.

2091-T3 SHEET  
(0.063"x79"x79")

TABLE B1

## TENSILE RESULTS FOR PECHINEY

2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
BOEING	RT	LONG	57.0	41.3	13.0		
			58.1	41.2	20.0		
			58.0	41.2	22.0		
LTV	RT	LONG	58.8		21.5		
			58.6	39.0	21.0		10.7
			58.2	39.4	19.5		11.0
GENERAL DYNAMICS, CALIF.	RT	LONG	56.7	41.1	20.0		10.7
			55.9	40.3	20.0		10.7
			56.5	41.7	18.5		10.7
NORTHROP			58.5	42.3	16.9		
			58.9	42.1	16.9		
			59.0	42.5	16.9		
MCAIR	RT	LONG	57.5	42.6	19.0		12.0
			57.0	42.4	16.0		12.1
			57.5	42.4	23.0		12.2
MARTIN MARIETTA, LOUISIANA	RT	LONG	56.1	39.4	18.0	27.0	
			57.6	40.8	20.0	21.0	
			59.2	42.5	22.0	25.0	
AVERAGE			57.7	41.3	19.1	24.3	11.3
STANDARD DEVIATION			1.0	1.2	2.5	3.1	0.7

TABLE B2

## TENSILE RESULTS FOR PECHINEY

2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
BOEING	RT	L TRANS	60.8	41.5	16.0		
			61.4	41.5	17.0		
			60.8	41.6	16.0		
NORTHROP	RT	L TRANS	62.0	41.9	17.0		
			62.7	41.6	16.8		
			62.0	42.0	17.1		
LTV	RT	L TRANS	61.7	40.0	17.0		10.7
			61.6	39.9	18.5		10.6
			61.9	39.3	16.5		11.0
GENERAL DYNAMICS, CALIF.	RT	L TRANS	60.0	41.3	22.0		10.9
			60.2	41.2	21.0		10.9
			59.7	41.4	20.0		10.9
MCAIR	RT	L TRANS	62.0	42.2	17.0		12.0
			60.5	42.7	17.0		12.0
			60.5	41.9	18.0		12.1
MARTIN MARIETTA, LOUISIANA	RT	L TRANS	60.8	41.2	17.0	27.0	
			60.5	40.8	16.0	21.0	
			60.3	40.9	16.0	24.0	
AVERAGE			61.1	41.3	17.6	24.0	11.2
STANDARD DEVIATION			0.9	0.9	1.8	3.0	0.6

TABLE B3

COMPRESSION RESULTS FOR PECHINEY  
2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
BOEING	RT	LONG	39.4 39.6 39.9	
LTV	RT	LONG	41.4 41.4	10.6 10.6
GENERAL DYNAMICS, CALIF.	RT	LONG	38.7 38.9 39.1	11.7 12.0 12.0
		AVERAGE	39.8	11.4
		STANDARD DEVIATION	1.0	0.7

TABLE B4

COMPRESSION RESULTS FOR PECHINEY  
2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
BOEING	RT	L TRANS	44.6 44.7 44.5	
LTV	RT	L TRANS	45.9 45.2 45.3	
GENERAL DYNAMICS, CALIF.	RT	L TRANS	42.7 44.3	11.8 11.5
		AVERAGE	44.7	11.7
		STANDARD DEVIATION	1.0	0.2

**TABLE B5**

**PUNCH SHEAR RESULTS FOR PECHINEY  
2091-T3 SHEET (0.063" X 79" X 39")**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<hr/>		
<b>BOEING</b>	<b>S TRANS</b>	<b>36.0</b>
		<b>36.5</b>
		<b>36.0</b>
	<b>AVERAGE</b>	<b>36.2</b>
	<b>STANDARD DEVIATION</b>	<b>0.3</b>

**TABLE B6**

**SLOTTED SHEAR RESULTS FOR PECHINEY  
2091-T3 SHEET (0.063" X 39" X 39")**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<hr/>		
<b>BOEING</b>	<b>LONG</b>	<b>39.8</b>
		<b>39.0</b>
		<b>36.9</b>
<b>LTV</b>	<b>LONG</b>	<b>38.3</b>
		<b>38.6</b>
		<b>37.9</b>
<b>MCAIR</b>	<b>LONG</b>	<b>38.1</b>
		<b>37.9</b>
		<b>38.2</b>
	<b>AVERAGE</b>	<b>38.3</b>
	<b>STANDARD DEVIATION</b>	<b>0.8</b>

**TABLE B7**  
**SLOTTED SHEAR RESULTS FOR PECHINEY**  
**2091-T3 SHEET (0.063" X 39" X 39")**

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
-----		
BOEING	T - L	36.8
		40.1
		36.4
LTV	T - L	40.0
		40.5
		40.5
MCAIR	T - L	39.2
		37.9
		39.0
AVERAGE		38.9
STANDARD DEVIATION		1.5

TABLE B8

## BEARING RESULTS FOR PECHINEY

2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
BOEING	LONG	1.5		88.9		61.4
				90.2		63.0
				90.3		63.5
LTV	LONG	1.5		90.4		58.9
				88.5		61.2
				89.3		61.4
GENERAL DYNAMICS, CALIF.	LONG	1.5		88.6		66.6
				88.1		64.0
				90.0		64.0
AVERAGE				89.4		62.7
STANDARD DEVIATION				0.9		2.2

TABLE B9

## BEARING RESULTS FOR PECHINEY

2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
BOEING	L TRANS	1.5		92.9		62.6
				93.1		63.3
				93.1		63.3
LTV	L TRANS	1.5		91.0		60.5
				92.1		59.7
				92.2		61.8
GENERAL DYNAMICS, CALIF.	L TRANS	1.5		90.3		65.7
				88.5		62.3
				87.9		64.0
AVERAGE				91.2		62.6
STANDARD DEVIATION				2.0		1.8

TABLE B10

## BEARING RESULTS FOR PECHINEY

2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
BOEING	LONG	2.0		115.2		75.6
				115.8		76.1
				115.3		76.2
LTV	LONG	2.0		111.6		77.3
				111.0		76.4
				112.5		76.9
GENERAL DYNAMICS, CALIF.	LONG	2.0		115.6		76.8
				114.3		73.2
MCAIR	LONG	2.0				73.5
						73.9
AVERAGE				113.9		75.6
STANDARD DEVIATION				1.9		

TABLE B11

## BEARING RESULTS FOR PECHINEY

2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	e/D	BEARING	
			ULT. STR. (KSI)	YIELD STR. (KSI)
BOEING	L TRANS	2.0	118.8	76.5
			115.2	75.4
LTV	L TRANS	2.0	111.1	75.9
			114.1	78.8
			116.0	75.1
GENERAL DYNAMICS, CALIF.	L TRANS	2.0	120.6	76.8
			115.9	81.8
			111.7	80.3
MCAIR	L TRANS	2.0		76.5
				72.7
AVERAGE			115.4	77.0
STANDARD DEVIATION			3.2	2.7

TABLE B12

General Dynamics, CA

ASTM E561 R Curve CCT Al-Li B-5-LT-1

W = 3.994 in      F<sub>ty</sub> = 41.10 ksi  
 B = 0.0644 in      P<sub>max</sub> = 7540 lb  
 a = 1.255 in  
 a/2 = 0.6275 in

a eff	Loads			Load	a (half)	a plastic	a eff	K
	5000	7540	10000					
0.6	28	43	57	0	0.6275	0.0000	0.6275	0
0.6	29	44	58	200	0.7225	0.0002	0.7227	1
0.7	30	45	59	600	0.7225	0.0014	0.7239	4
0.7	30	46	61	1000	0.7225	0.0038	0.7263	6
0.7	31	47	62	1400	0.7225	0.0075	0.7300	9
0.7	32	48	64	1800	0.7225	0.0124	0.7349	12
0.8	33	49	65	2200	0.7225	0.0186	0.7411	14
0.8	33	51	67	2600	0.7225	0.0259	0.7484	17
0.8	34	52	69	2800	0.7250	0.0302	0.7552	18
0.8	35	53	70	3200	0.7250	0.0395	0.7645	21
0.9	36	54	72	3600	0.7250	0.0499	0.7749	24
0.9	37	55	73	4000	0.7275	0.0619	0.7894	27
0.9	38	57	75	4400	0.7275	0.0750	0.8025	30
0.9	38	58	77	4600	0.7275	0.0819	0.8094	32
1.0	39	59	78	4800	0.7300	0.0896	0.8196	33
1.0	40	60	80	5200	0.7300	0.1052	0.8352	37
1.0	41	62	82	5600	0.7300	0.1220	0.8520	40
1.0	42	63	84	5800	0.7300	0.1309	0.8609	42
1.1	43	65	86	6000	0.7450	0.1440	0.8890	45
1.1	44	66	88	6200	0.7450	0.1538	0.8988	46
1.1	45	68	90	6400	0.7600	0.1685	0.9285	49
				6800	0.7600	0.1902	0.9502	53
				7000	0.7700	0.2053	0.9753	56
				7200	0.7700	0.2172	0.9872	58
				7400	0.7850	0.2359	1.0209	62

$$K_c = 61.8 \text{ Ksi} \sqrt{\text{in}}$$

ASTM E561 R-Curve Chart  
Alum-Li, Spec. B-5-LT-1

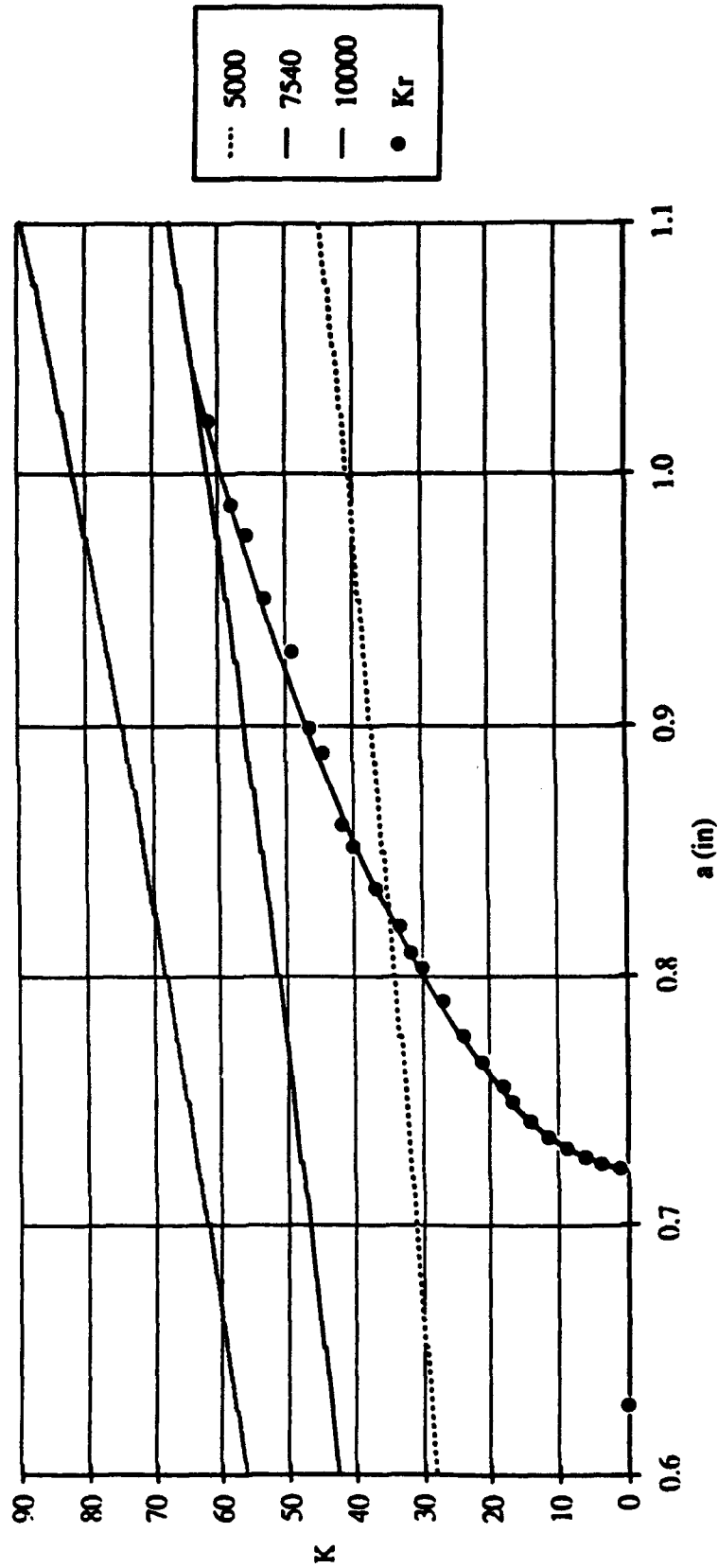


Figure B1 R-Curve Results for 2091-T3 0.063" Sheet (LT) General Dynamics, CA.

TABLE B13

General Dynamics, CA

ASTM E561 R Curve CCT Al-Li B-5-LT-2

W = 3.995 in      F<sub>ty</sub> = 41.10 ksi  
 B = 0.0647 in      P<sub>max</sub> = 7250 lb  
 a = 1.255 in  
 a/2 = 0.6275 in

Loads								
a eff	5000	7250	10000	Load	a (half)	a plastic	a eff	K
0.6	28	41	56	0	0.6275	0.0000	0.6275	0
0.6	29	42	58	200	0.7250	0.0002	0.7252	1
0.7	30	43	59	600	0.7250	0.0014	0.7264	4
0.7	30	44	61	1000	0.7250	0.0038	0.7288	6
0.7	31	45	62	1400	0.7250	0.0075	0.7325	9
0.7	32	46	64	1800	0.7250	0.0124	0.7374	12
0.8	33	47	65	2200	0.7250	0.0185	0.7435	14
0.8	33	48	67	2600	0.7250	0.0258	0.7508	17
0.8	34	49	68	2800	0.7250	0.0299	0.7549	18
0.8	35	51	70	3200	0.7250	0.0391	0.7641	21
0.9	36	52	71	3600	0.7250	0.0494	0.7744	24
0.9	36	53	73	4000	0.7275	0.0613	0.7888	27
0.9	37	54	75	4200	0.7275	0.0676	0.7951	29
0.9	38	55	76	4400	0.7300	0.0746	0.8046	30
1.0	39	57	78	4600	0.7300	0.0815	0.8115	32
1.0	40	58	80	4800	0.7300	0.0887	0.8187	33
1.0	41	59	82	5200	0.7300	0.1041	0.8341	37
1.0	42	60	83	5600	0.7300	0.1208	0.8508	40
1.1	43	62	85	5800	0.7300	0.1296	0.8596	42
1.1	44	63	87	6000	0.7300	0.1387	0.8687	44
1.1	45	65	89	6200	0.7325	0.1488	0.8813	46
				6400	0.7325	0.1585	0.8910	47
				6800	0.7375	0.1806	0.9181	52
				7000	0.7450	0.1941	0.9391	54
				7200	0.7550	0.2092	0.9642	57

$$K_c = 56.9 \text{ Ksi } \sqrt{in}$$

ASTM E561 R-Curve Chart  
Alum-Li, Spec. B-5-LT-2

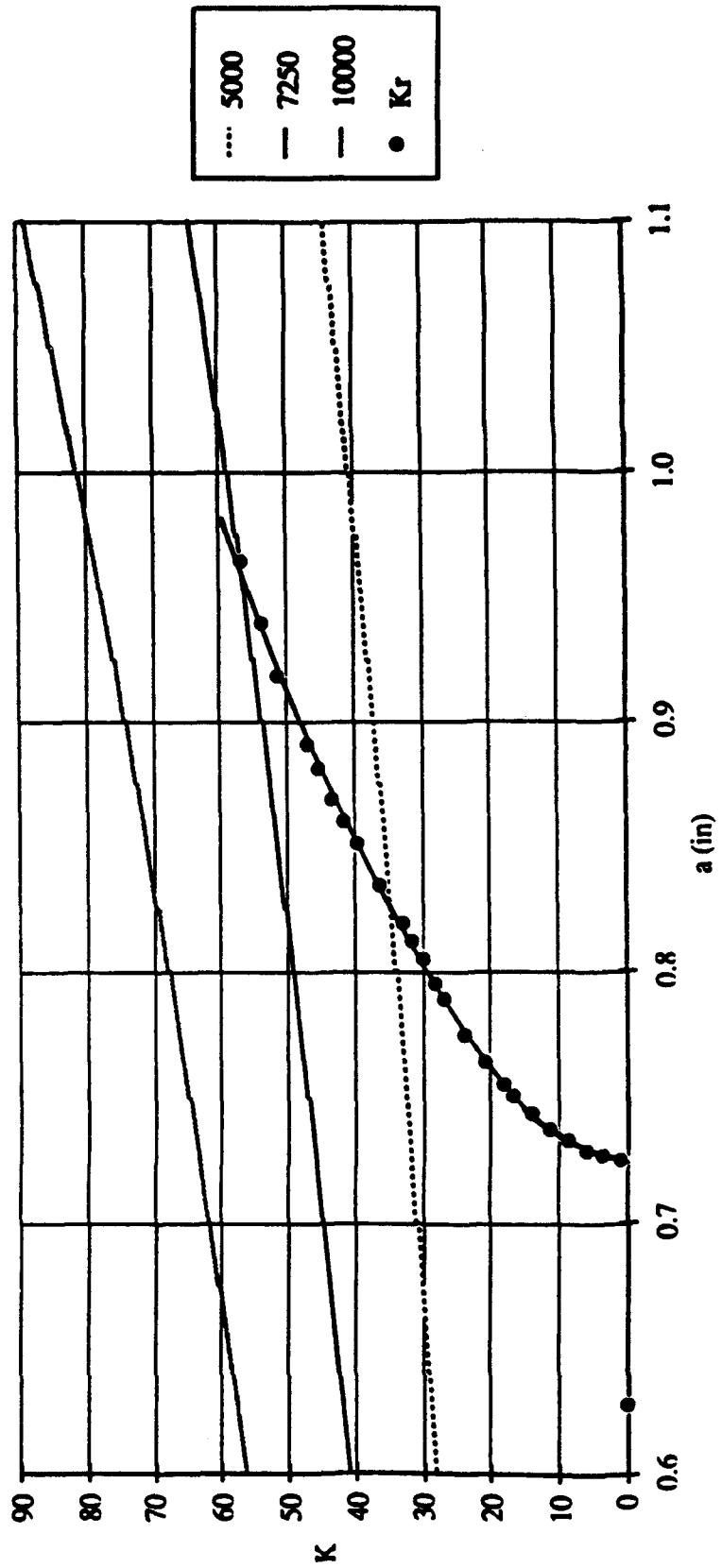


Figure B2 R-Curve Results for 2091-T3 0.063" Sheet (LT). General Dynamics, CA.

TABLE B14

General Dynamics, CA

ASTM E561 R Curve

CCT Al-Li B-5-LT-3

$W = 3.992$  in       $F_{ty} = 41.10$  ksi  
 $B = 0.0642$  in       $P_{max} = 5875$  lb  
 $a = 1.2600$  in  
 $a/2 = 0.6300$  in

a eff	Loads			Load	a (half)	a plastic	a eff	K
	4000	5875	8000					
0.6	23	33	45	0	0.6300	0.0000	0.6300	0
0.6	23	34	47	200	0.7275	0.0002	0.7277	1
0.7	24	35	48	600	0.7275	0.0014	0.7289	4
0.7	24	36	49	1000	0.7275	0.0039	0.7314	6
0.7	25	37	50	1400	0.7275	0.0076	0.7351	9
0.7	26	38	51	1800	0.7275	0.0126	0.7401	12
0.8	26	39	53	2000	0.7275	0.0156	0.7431	13
0.8	27	40	54	2200	0.7275	0.0189	0.7464	14
0.8	28	40	55	2600	0.7275	0.0264	0.7539	17
0.8	28	41	56	3000	0.7275	0.0351	0.7626	20
0.9	29	42	58	3400	0.7275	0.0451	0.7726	23
0.9	29	43	59	3800	0.7275	0.0563	0.7838	26
0.9	30	44	60	4200	0.7275	0.0688	0.7963	29
0.9	31	45	62	4400	0.7275	0.0755	0.8030	30
1.0	31	46	63	4600	0.7275	0.0825	0.8100	32
1.0	32	47	64	4800	0.7275	0.0899	0.8174	34
1.0	33	48	66	5000	0.7275	0.0975	0.8250	35
				5200	0.7275	0.1055	0.8330	37
				5400	0.7275	0.1137	0.8412	39
				5600	0.7275	0.1223	0.8498	40
				5800	0.7275	0.1312	0.8587	42

~~$K_{IC} = 42.1 \text{ ksi}\sqrt{\text{in}}$~~  Specimen failed  
 in doubler region

ASTM E561 R-Curve Chart  
Alum-Li, Spec. B-5-LT-3

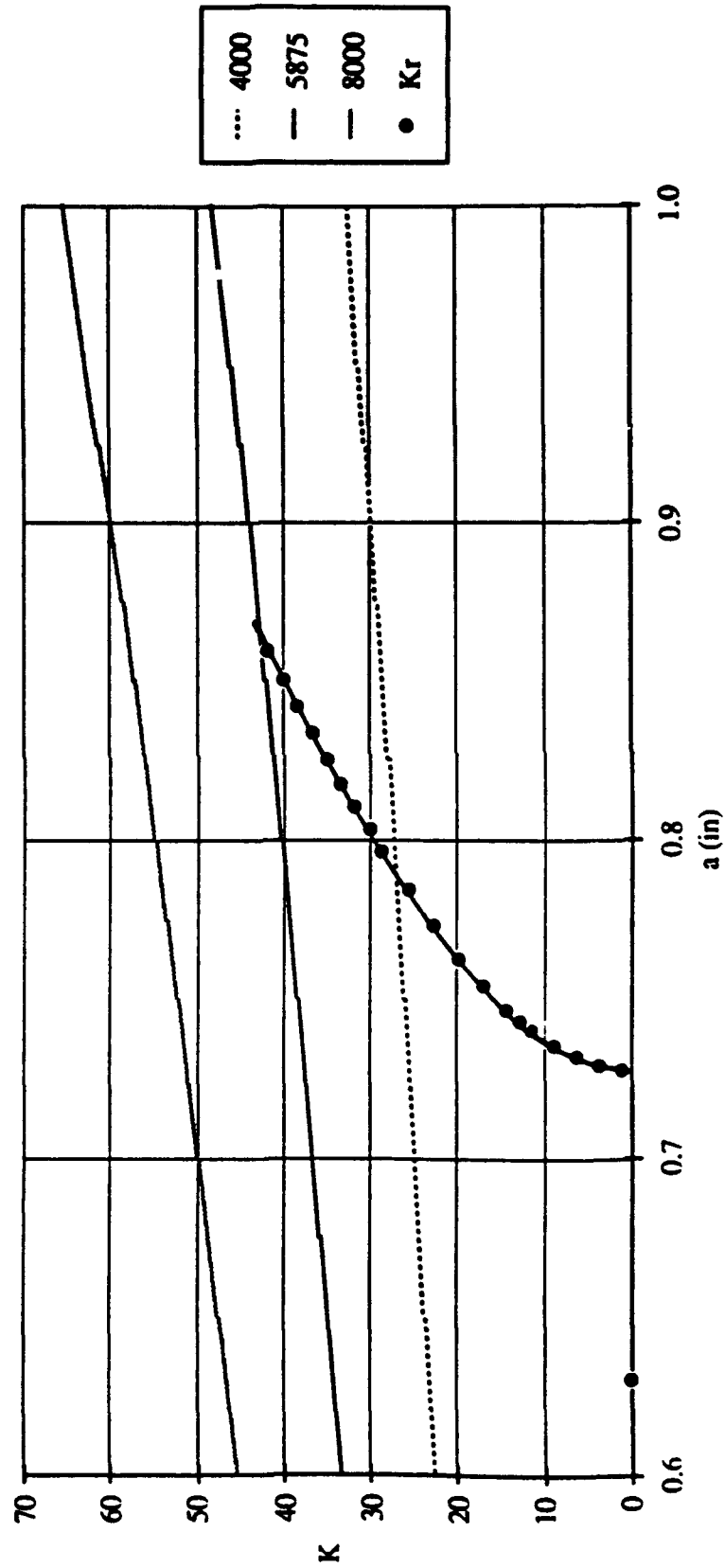


Figure B3 R-Curve Results for 2091-T3 0.063" Sheet (1T). General Dynamics, CA.

TABLE B15

General Dynamics, CA

ASTM E561 R Curve CCT Al-Li B-5-TL-1

W = 3.995 in      F<sub>ty</sub> = 41.10 ksi  
 B = 0.0649 in      P<sub>max</sub> = 7290 lb  
 a = 1.25 in  
 a/2 = 0.625 in

a eff	Loads			Load	a (half)	a plastic	a eff	K
	5000	7290	10000					
0.6	28	41	56	0	0.6250	0.0000	0.6250	0
0.6	29	42	58	200	0.7400	0.0002	0.7402	1
0.7	30	43	59	600	0.7400	0.0014	0.7414	4
0.7	30	44	60	1000	0.7400	0.0039	0.7439	6
0.7	31	45	62	1400	0.7400	0.0076	0.7476	9
0.7	32	46	63	1600	0.7425	0.0100	0.7525	10
0.8	32	47	65	2000	0.7425	0.0157	0.7582	13
0.8	33	48	66	2400	0.7425	0.0226	0.7651	16
0.8	34	50	68	2800	0.7425	0.0307	0.7732	19
0.8	35	51	70	3200	0.7425	0.0401	0.7826	21
0.9	36	52	71	3600	0.7425	0.0508	0.7933	24
0.9	36	53	73	4000	0.7425	0.0627	0.8052	27
0.9	37	54	74	4400	0.7425	0.0759	0.8184	30
0.9	38	55	76	4600	0.7425	0.0829	0.8254	32
1.0	39	57	78	4800	0.7450	0.0907	0.8357	34
1.0	40	58	80	5000	0.7475	0.0989	0.8464	35
1.0	41	59	81	5200	0.7525	0.1079	0.8604	37
1.0	42	61	83	5600	0.7525	0.1252	0.8777	41
1.1	43	62	85	6000	0.7525	0.1437	0.8962	44
1.1	44	63	87	6200	0.7550	0.1542	0.9092	47
1.1	45	65	89	6400	0.7575	0.1650	0.9225	49
				6600	0.7575	0.1755	0.9330	51
				6800	0.7625	0.1881	0.9506	53
				7000	0.7625	0.1993	0.9618	55
				7200	0.7950	0.2238	1.0188	60

$$K_c = 59.6 \text{ Ksi} \sqrt{\text{in}}$$

ASTM E561 R-Curve Chart  
Alum-Li, Spec. B-5-TL-1

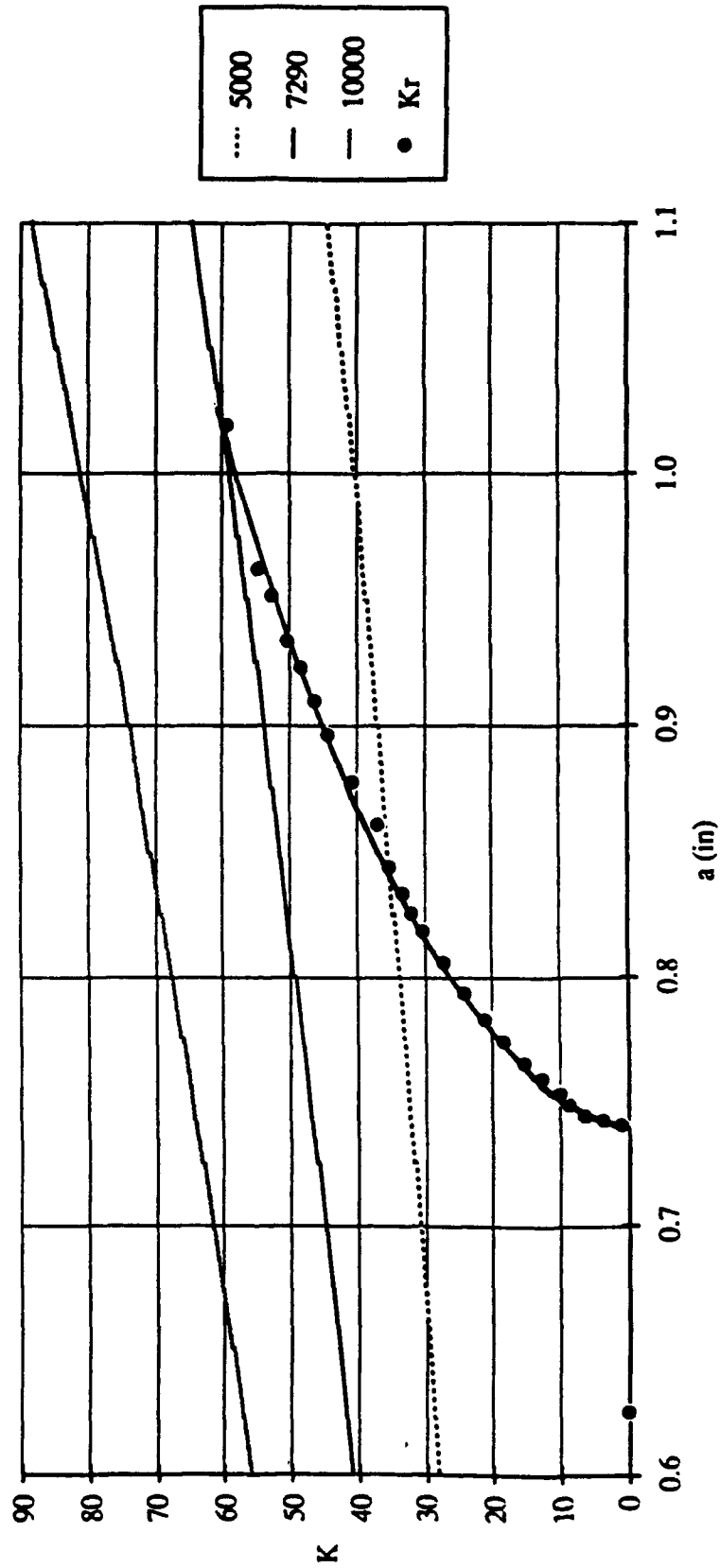


Figure B4 R-Curve Results for 2091-T3 0.063" Sheet (TL). General Dynamics, CA.

TABLE B16

General Dynamics, CA

ASTM E561 R Curve

CCT Al-Li B-5-TL-2

W = 3.992 in

Fty = 41.10 ksi

B = 0.0646 in

Pmax = 7450 lb

a = 1.2550 in

a/2 = 0.6275 in

Loads								
a eff	5000	7450	10000	Load	a (half)	a plastic	a eff	K
0.6	28	42	56	0	0.6275	0.0000	0.6275	0
0.6	29	43	58	200	0.7275	0.0002	0.7277	1
0.7	30	44	59	400	0.7275	0.0006	0.7281	3
0.7	30	45	61	600	0.7325	0.0014	0.7339	4
0.7	31	46	62	1000	0.7325	0.0039	0.7364	6
0.7	32	48	64	1400	0.7325	0.0076	0.7401	9
0.8	33	49	65	1800	0.7325	0.0126	0.7451	12
0.8	33	50	67	2200	0.7325	0.0188	0.7513	14
0.8	34	51	68	2600	0.7325	0.0263	0.7588	17
0.8	35	52	70	3000	0.7325	0.0350	0.7675	20
0.9	36	53	72	3400	0.7325	0.0450	0.7775	23
0.9	37	55	73	3600	0.7425	0.0513	0.7938	24
0.9	37	56	75	3800	0.7425	0.0572	0.7997	26
0.9	38	57	77	4000	0.7450	0.0637	0.8087	28
1.0	39	58	78	4200	0.7450	0.0702	0.8152	29
1.0	40	60	80	4400	0.7525	0.0781	0.8306	31
1.0	41	61	82	4600	0.7525	0.0854	0.8379	33
1.0	42	62	84	4800	0.7550	0.0934	0.8484	34
1.1	43	64	86	5400	0.7550	0.1183	0.8733	39
1.1	44	65	88	5600	0.7575	0.1278	0.8853	41
1.1	45	67	90	6000	0.7575	0.1467	0.9042	45
				6200	0.7600	0.1573	0.9173	47
				6400	0.7600	0.1677	0.9277	49
				6600	0.7675	0.1808	0.9483	52
				6800	0.7725	0.1937	0.9662	54
				7000	0.7800	0.2081	0.9881	57
				7200	0.7875	0.2232	1.0107	59
				7400	0.8025	0.2423	1.0448	63

$$K_c = 63.0 \text{ Ksi} \sqrt{\text{in}}$$

ASTM E561 R-Curve Chart  
Alum-Li, Spec. B-5-TL-2

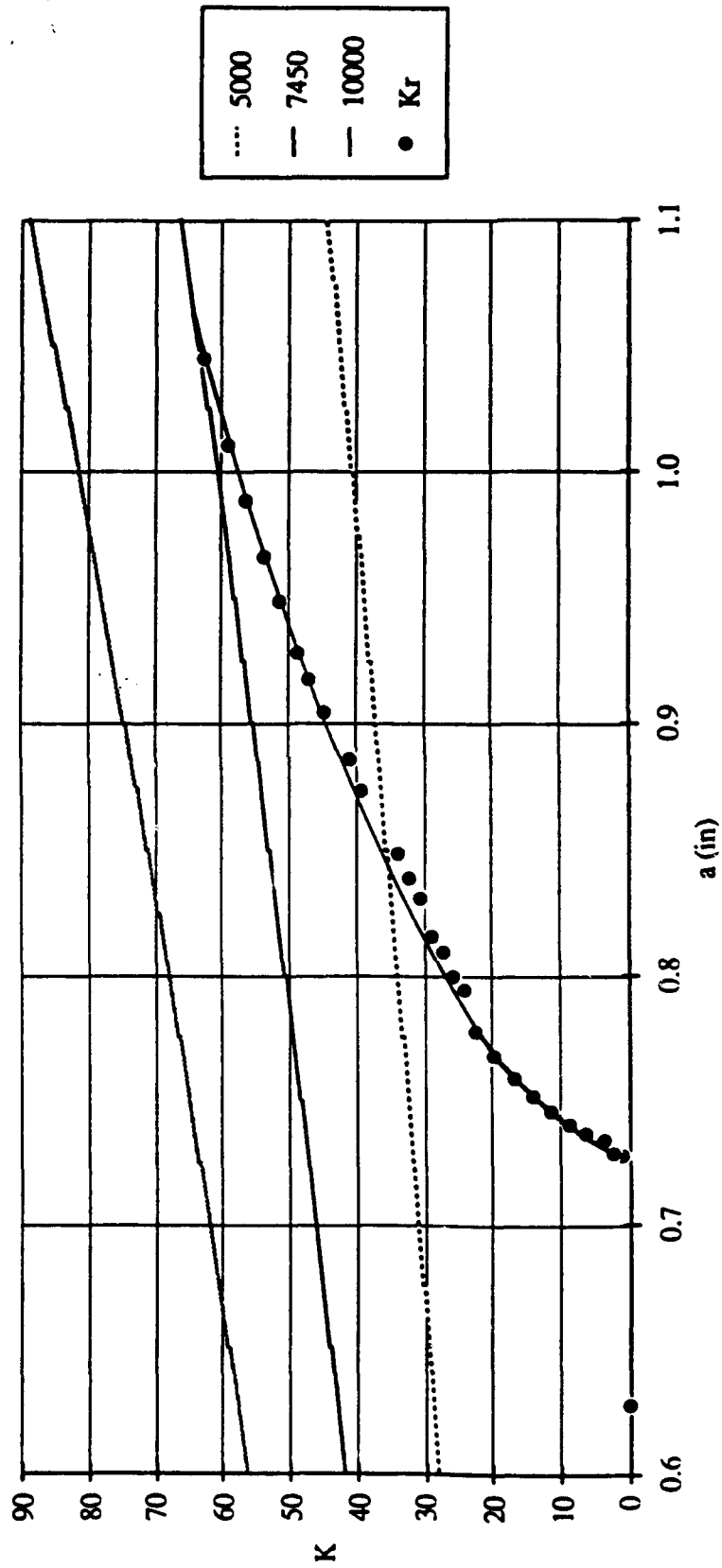


Figure B5 R-Curve Results for 2091-T3 0.063" Sheet (TL). General Dynamics, CA

TABLE B17

General Dynamics, CA

ASTM E561 R Curve

CCT Al-Li B-5-TL-3

W = 3.996 in  
 B = 0.0642 in  
 a = 1.2500 in  
 a/2 = 0.6250 in

F<sub>ty</sub> = 41.10 ksi  
 P<sub>max</sub> = 7290 lb

a eff	Loads			Load	a (half)	a plastic	a eff	K
	5000	7290	10000					
0.6	28	41	57	0	0.6250	0.0000	0.6250	0
0.6	29	42	58	200	0.7250	0.0002	0.7252	1
0.7	30	43	60	600	0.7250	0.0014	0.7264	4
0.7	31	45	61	1000	0.7250	0.0039	0.7289	6
0.7	31	46	63	1400	0.7250	0.0076	0.7326	9
0.7	32	47	64	1800	0.7250	0.0125	0.7375	12
0.8	33	48	66	2000	0.7250	0.0155	0.7405	13
0.8	34	49	67	2400	0.7250	0.0223	0.7473	16
0.8	34	50	69	2800	0.7250	0.0304	0.7554	18
0.8	35	51	70	3200	0.7250	0.0397	0.7647	21
0.9	36	52	72	3600	0.7250	0.0502	0.7752	24
0.9	37	54	74	3800	0.7250	0.0559	0.7809	26
0.9	38	55	75	4200	0.7250	0.0683	0.7933	29
0.9	38	56	77	4600	0.7250	0.0820	0.8070	32
1.0	39	57	79	4800	0.7250	0.0892	0.8142	33
1.0	40	59	80	5200	0.7250	0.1047	0.8297	37
1.0	41	60	82	5600	0.7250	0.1215	0.8465	40
1.0	42	61	84	5800	0.7250	0.1303	0.8553	42
1.1	43	63	86	6000	0.7250	0.1394	0.8644	44
1.1	44	64	88	6400	0.7250	0.1586	0.8836	47
1.1	45	66	90	6600	0.7250	0.1687	0.8937	49
				6800	0.7250	0.1791	0.9041	51
				7000	0.7250	0.1898	0.9148	53
				7200	0.7250	0.2008	0.9258	55

$$K_c = 55.4 \text{ Ksi} \sqrt{\text{in}}$$

ASTM E561 R-Curve Chart  
Alum-Li, Spec. B-5-TL-3

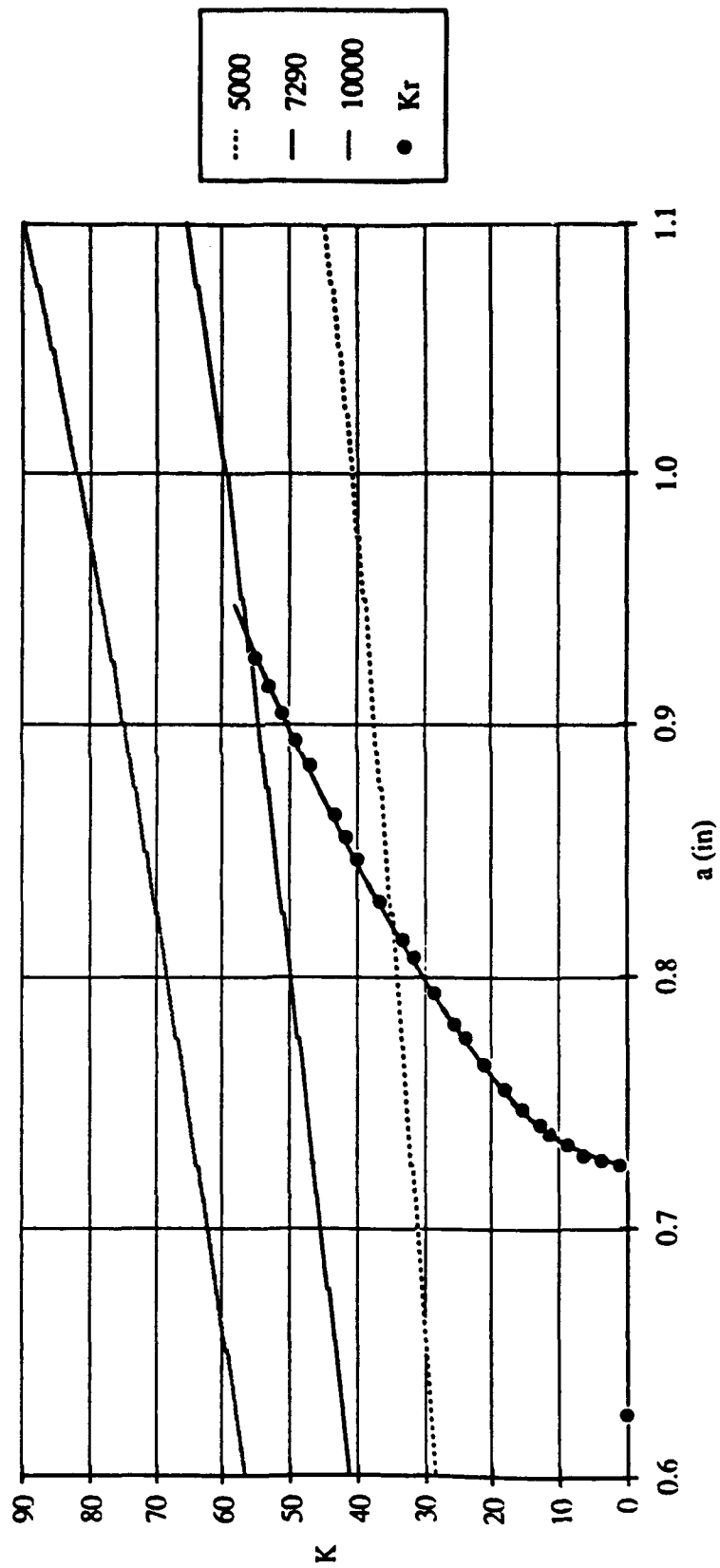


Figure B6 R-Curve Results for 2091-T3 0.063" Sheet (TL). General Dynamics, CA.

TABLE B18

MCAIR

R-CURVE TOUGHNESS DATA FOR PETCHINCV 2091  
ALUMINUM LITHIUM ALLOY

SPECIMEN IDENTIFICATION	ORIENTATION	SLOT LENGTH 2a, (IN)	PRECRACK LENGTH 2a, (IN)	FINAL CRACK LENGTH 2a, (IN)	LOAD AT FAILURE (LB)	PLANE STRESS FRACTURE TOUGHNESS, K <sub>IC</sub> , (KSI(IN) <sup>0.5</sup> )
1	LI-L	1.9915	2.1006	2.2480	10,900	57.0
2		1.9945	2.1000	2.2566	10,980	57.4
AVERAGE		-----	-----	-----	10,940	57.2
3	L-LI	1.9925	2.0993	2.2120	10,740	57.1
4		1.9965	2.1015	2.1815	10,900	55.9
AVERAGE		-----	-----	-----	10,820	56.5

DATA COLLECTED AND REDUCED PER ASTM STANDARD TEST METHOD E561-81.

The four toughness specimens were tested in accordance with ASTM Standard Test Method E561-81. The specimens were precracked to a total crack length, 2a, equal to 35% of the width, as is required per the standard. A stress ratio of 0.1 was used for precracking. The specimens were statically failed using a loading rate of 3000 pound/minute. Cathetometers were used to monitor crack length during static loading to determine the final crack length, at failure, which is required for toughness calculations. Table B18 presents toughness test data. All four specimens had a plane stress toughness value in the range of 56 to 57 ksi(in)<sup>0.5</sup>. It should be noted that no plastic zone corrections were incorporated into the toughness calculations.

**R-CURVE FOR 2091 SHEET (longitudinal)**  
(effective crack length adjusted for plastic zone)

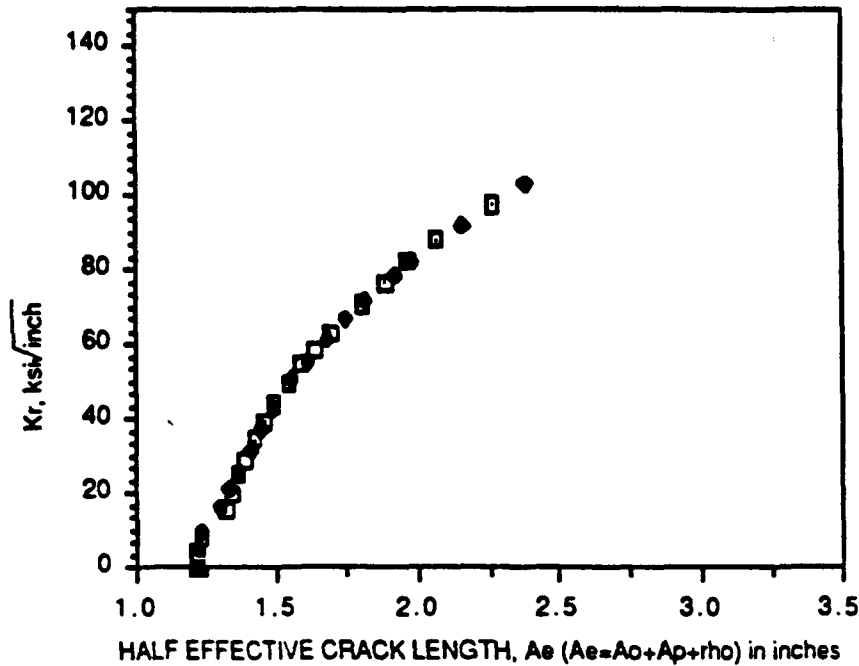


Figure B7 R-Curve Results for 2091-T3 0.063" Sheet (longitudinal).  
Martin Marietta, IA.

**R-CURVE FOR 2091 SHEET (transverse)**  
(effective crack length adjusted for plastic zone)

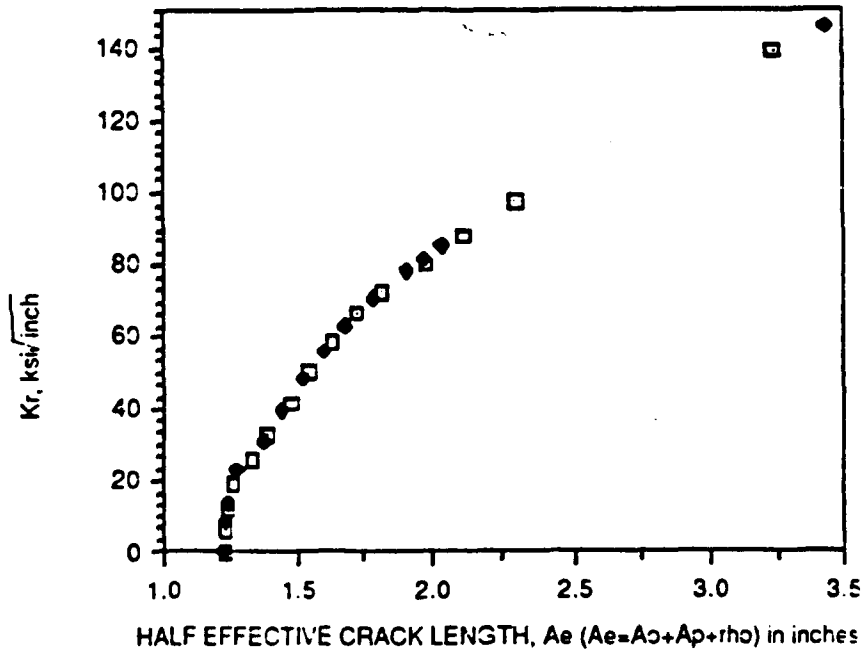


Figure B8 R-Curve Results for 2091-T3 0.063" Sheet (transverse).  
Martin Marietta

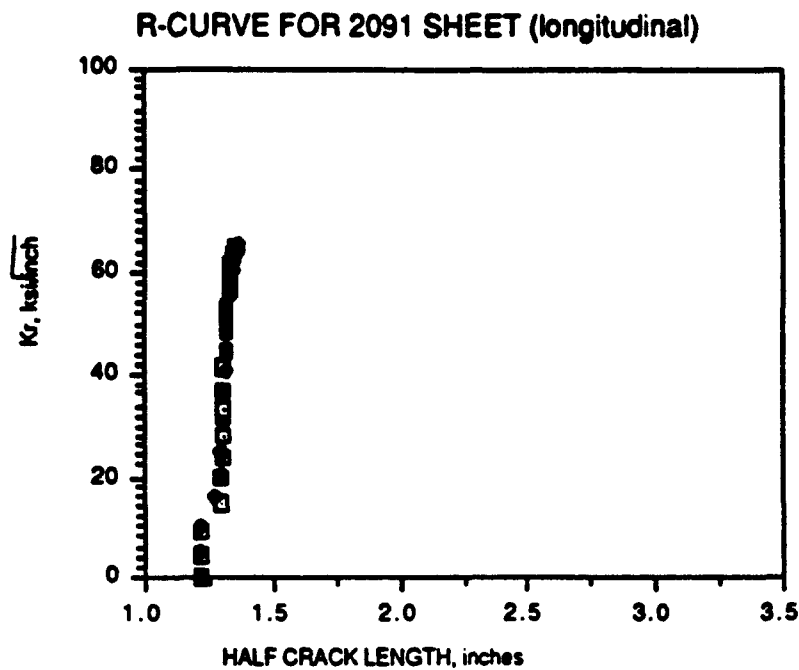


Figure B9 R-Curve Results for 2091-T3 0.063" Sheet (longitudinal).  
Martin Marietta, LA.

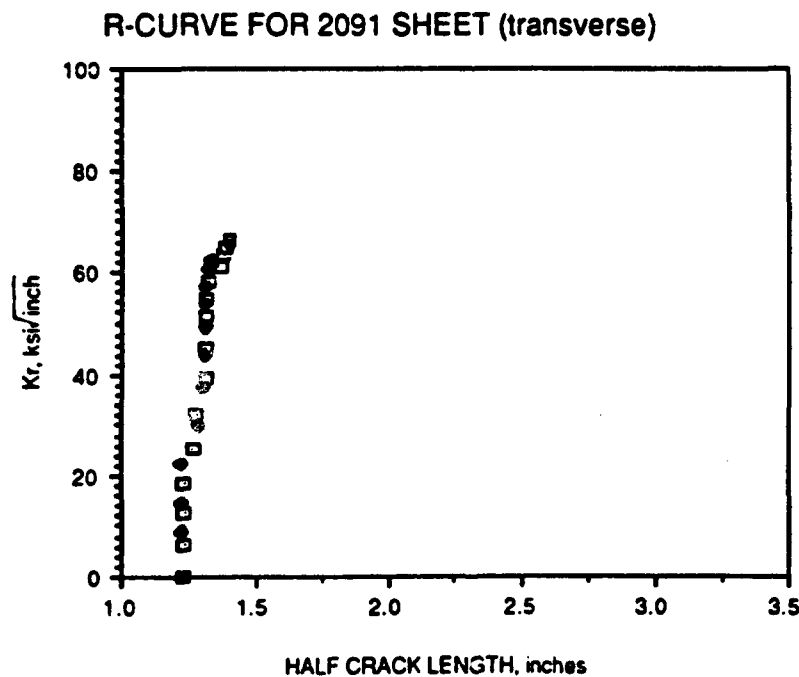


Figure B10 R-Curve Results for 2091-T3 0.063" Sheet (transverse).  
Martin Marietta, LA.

TABLE B19

Martin Marietta, LA

DATA FOR SPECIMEN NO. 4, 2091

## LONGITUDINAL SHEET

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not Adjusted	Adjusted for Plasticity
0.0	1.215	1.215	0.0	0.0
1.17	1.215	1.217	4.81	4.55
2.54	1.220	1.229	10.47	9.86
3.71	1.270	1.294	15.69	15.85
4.79	1.295	1.336	20.51	20.87
5.76	1.300	1.361	24.73	25.35
7.08	1.310	1.406	30.54	31.71
8.21	1.310	1.442	35.42	37.24
9.38	1.315	1.493	40.56	43.31
10.41	1.320	1.560	45.13	50.26
11.28	1.320	1.615	48.90	55.05
12.07	1.325	1.680	52.45	61.05
12.70	1.330	1.756	55.30	66.92
13.29	1.330	1.821	57.90	71.84
13.78	1.340	1.919	60.33	78.02
14.12	1.345	1.986	61.97	82.10
14.51	1.365	2.159	64.30	91.36
14.80	1.370	2.361	65.74	103.09

Thickness = .063 inch  
 Yield = 40.9 ksi  
 Specimen width = 8.00 inch

TABLE B20

Martin Marietta, LA

DATA FOR SPECIMEN NO. 5 2091

LONGITUDINAL SHEET

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not Adjusted	Adjusted for Plasticity
0.0	1.220	1.220	0.0	0.0
1.06	1.220	1.222	4.37	4.12
2.09	1.220	1.226	8.62	8.12
3.46	1.295	1.317	14.90	15.04
4.67	1.300	1.340	20.05	20.36
5.55	1.305	1.362	23.88	24.46
6.53	1.310	1.390	28.17	29.09
7.62	1.310	1.442	32.67	34.33
8.52	1.310	1.453	36.76	38.80
9.54	1.310	1.494	41.16	44.03
10.32	1.315	1.549	44.63	49.59
11.14	1.315	1.599	46.17	54.60
11.74	1.315	1.640	50.77	56.47
12.39	1.320	1.699	53.71	63.08
13.19	1.330	1.809	57.46	70.97
13.71	1.335	1.891	59.77	76.77
14.71	1.335	1.974	61.88	81.95
14.52	1.340	2.076	63.57	87.94
14.79	1.355	2.262	65.22	97.62

Thickness = .063 inch  
 Yield = 40.9 ksi  
 Specimen Width = 8.00 inch

TABLE B21

Martin Marietta, LA

DATA FOR SPECIMEN NO. 6 2091

## TRANSVERSE SHEET

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not Adjusted	Adjusted for Plasticity
0.0	1.215	1.215	0.0	0.0
2.19	1.215	1.222	9.01	8.49
3.50	1.220	1.238	14.43	13.60
5.47	1.220	1.271	22.56	23.05
7.00	1.282	1.373	29.79	30.90
8.75	1.295	1.445	37.47	39.65
10.16	1.300	1.521	43.61	48.23
11.43	1.300	1.605	49.19	56.11
12.43	1.305	1.680	53.49	62.77
13.31	1.305	1.761	57.28	70.74
13.95	1.320	1.906	60.48	78.51
14.21	1.327	1.965	61.83	81.87
14.42	1.330	2.028	62.82	85.66
14.62	1.395	3.433	65.73	146.00

Thickness = .063 inch

Yield = 40.9 ksi

Specimen width = 8.00 inch

TABLE B22

Martin Marietta, IA

DATA FOR SPECIMEN NO. 7, 2091

## TRANSVERSE SHEET

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not Adjusted	Adjusted for Plasticity
0.0	1.225	1.225	0.0	0.0
1.52	1.225	1.228	6.28	5.92
3.00	1.225	1.238	12.40	11.66
4.51	1.225	1.259	18.65	18.92
7.00	1.260	1.324	25.20	25.94
7.50	1.275	1.380	31.81	33.16
9.11	1.305	1.470	39.20	41.69
10.51	1.305	1.547	45.23	50.43
11.86	1.305	1.635	51.04	58.91
12.74	1.310	1.729	54.96	66.33
13.40	1.320	1.817	58.09	72.27
13.65	1.360	1.977	61.40	80.55
14.28	1.375	2.107	63.58	87.73
14.56	1.390	2.299	65.30	97.73
14.77	1.400	3.245	66.56	139.00

Thickness = .063 inch  
 Yield = 40.9 ksi  
 Specimen width = 8.00 inch

**TABLE B23**

**FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR  
PECHINEY 2091-T3 SHEET (0.063" X 79" X 39")**

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
GENERAL DYNAMICS, CALIF.	LONG	21.8	10,000,000 *
		25.0	1,888,000
		27.0	10,140,000 *
		30.0	303,000
		32.0	363,000
		35.0	143,000
		38.0	122,000

(\*): INDICATES A RUN-OUT TEST

**TABLE B24**

**FATIGUE RESULTS WITH R=0.1 AND Kt=3.0 FOR  
PECHINEY 2091-T3 SHEET (0.063" X 79" X 39")**

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
GENERAL DYNAMICS, CALIF.	LONG	10.0	10,000,000 *
		12.0	319,000
		13.0	10,330,000 *
		13.5	193,000
		14.5	158,000
		16.0	163,000
		20.0	47,000
		25.0	15,000

(\*): INDICATES A RUN-OUT TEST

TABLE B25

FATIGUE RESULTS WITH R=0.1 AND Kt=2.8 FOR  
PECHINEY 2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
LTV	LONG	15.4	1,000,000 *
		15.4	410,760
		15.5	700,100
		16.5	192,020
		16.5	236,950
		18.5	202,250
		18.7	203,450 #
		19.0	155,800
		22.1	83,190
		22.4	76,450
		22.4	49,000

(\*): INDICATES A RUN-OUT TEST

(#): INDICATES SPECIMEN FAILED IN GRIP

TABLE B26

FATIGUE RESULTS WITH R=0.1 AND Kt=2.8 FOR  
PECHINEY 2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
LTV	L TRANS	15.5	1,500,000 *
		16.0	369,700
		18.7	94,490
		18.7	138,430
		22.1	84,900
		22.5	52,100

(\*): INDICATES A RUN-OUT TEST

# Pechiney 2091-T3 Sheet (0.063" x 79" x 39")

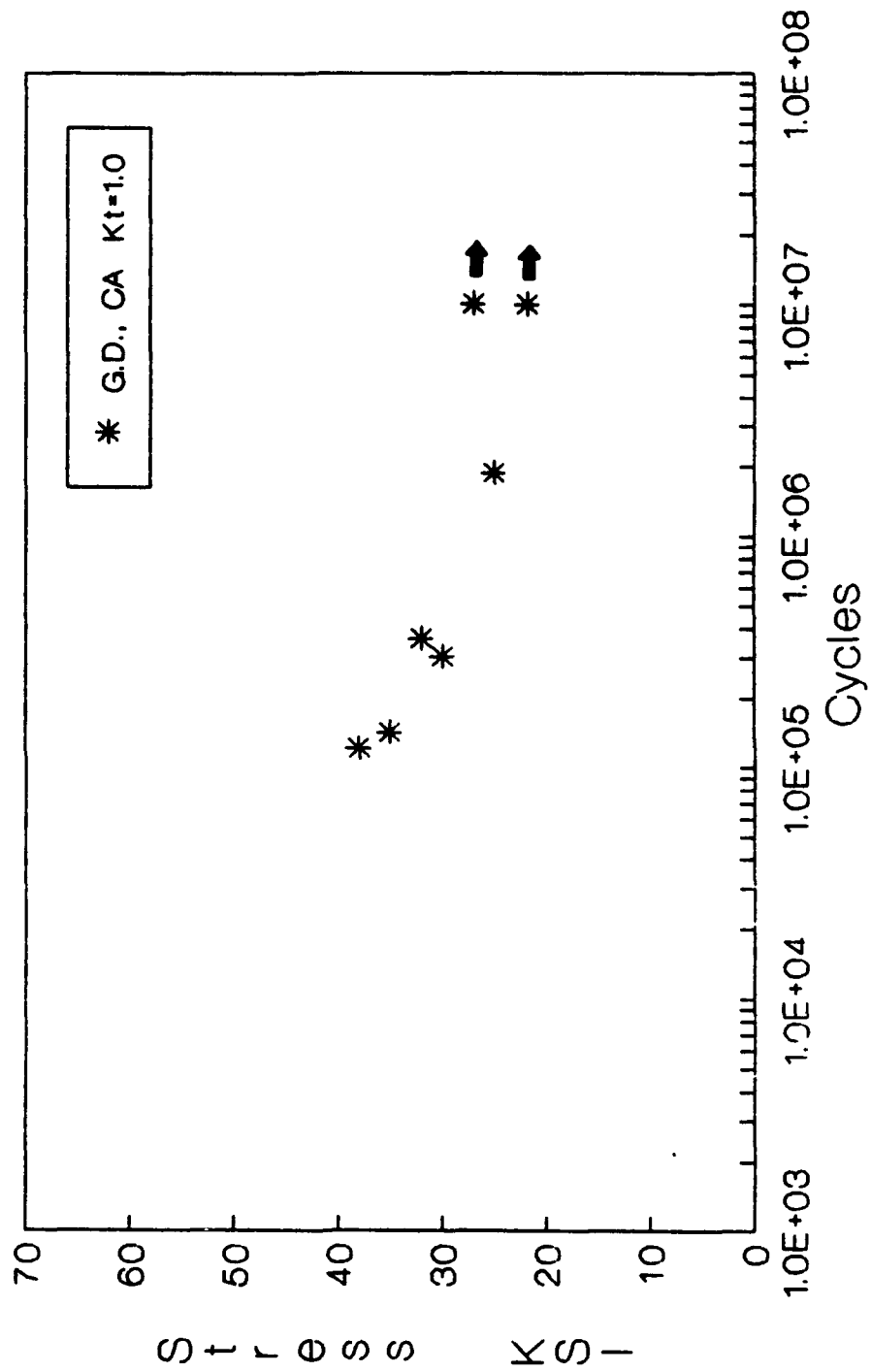


Figure B11 Fatigue Results for 2091-T3 0.063" Sheet ( $R=0.1$ ,  $K_t=1.0$ , and longitudinal). General Dynamics, CA

# Pechiney 2091-T3 Sheet (0.063" X 79" X 39")

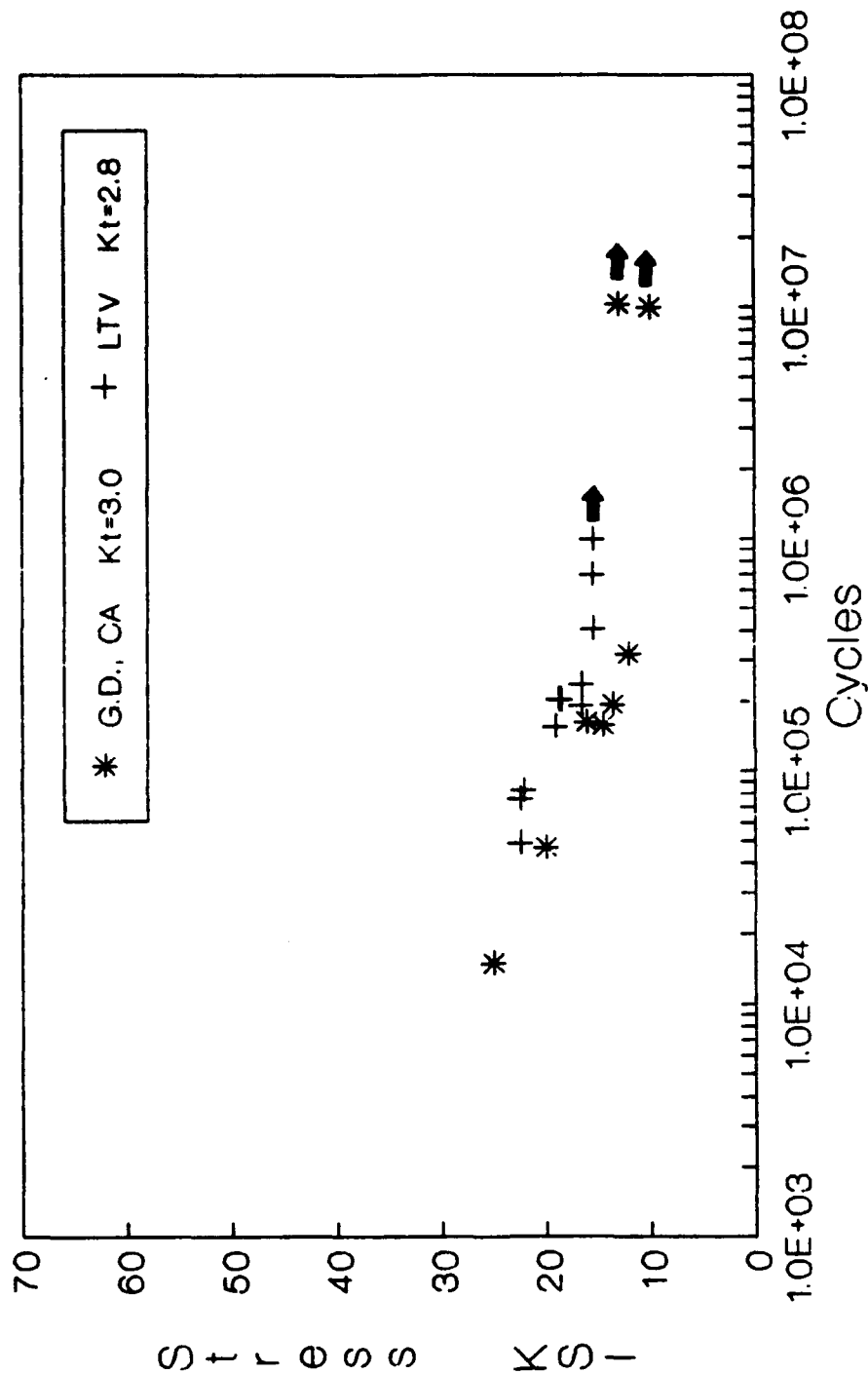


Figure B12 Fatigue Results for 2091-T3 0.063" Sheet (R=0.1,  $K_t \geq 2.8$ , and Longitudinal). General Dynamics, CA and LTV.

# Pechiney 2091-T3 Sheet (0.063" x 79" x 39")

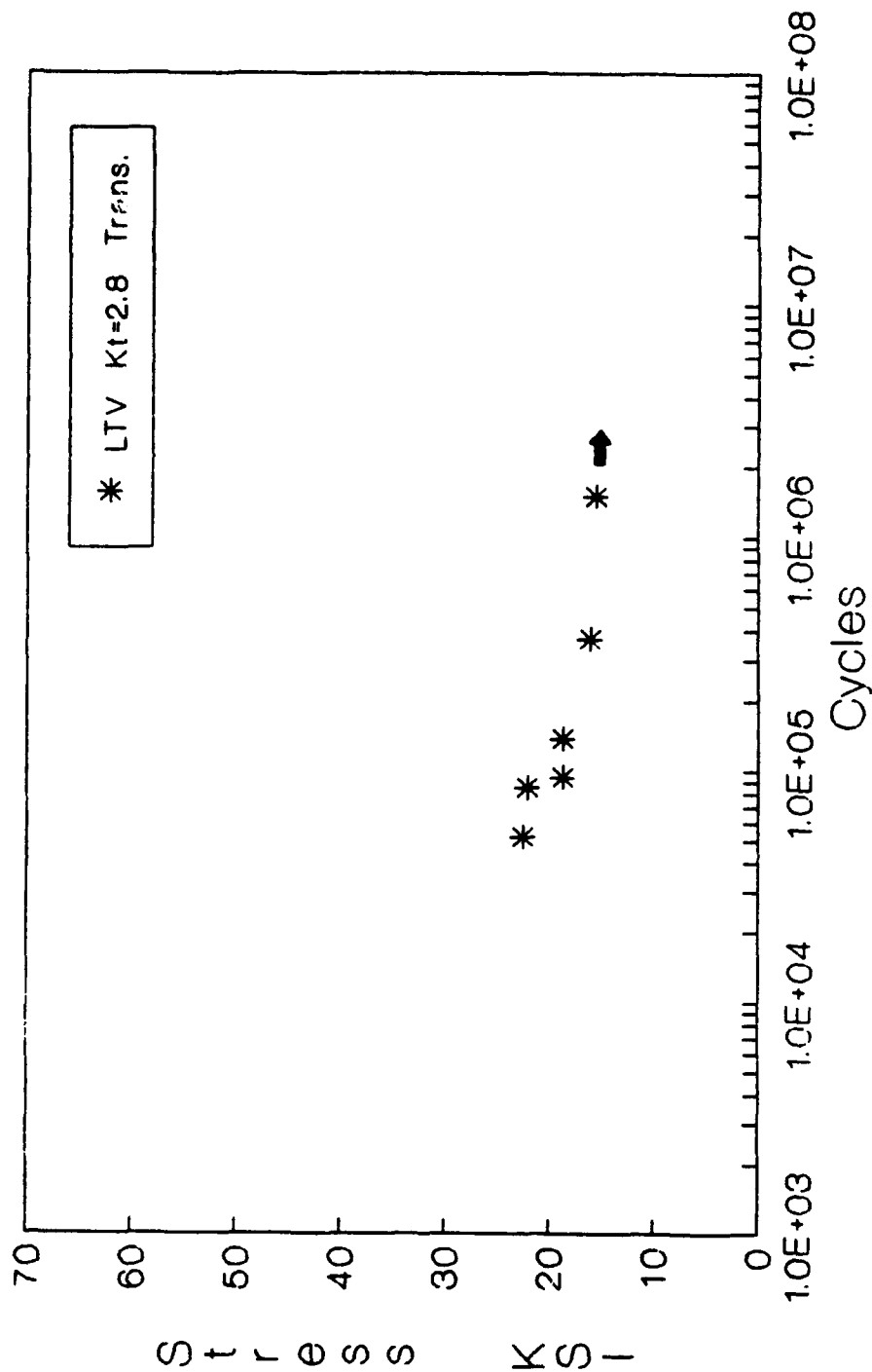


Figure B13 Fatigue Results for 2091-T3 0.063" Sheet ( $R=0.1$ ,  $K_t=2.8$ , and Transverse). LTV.

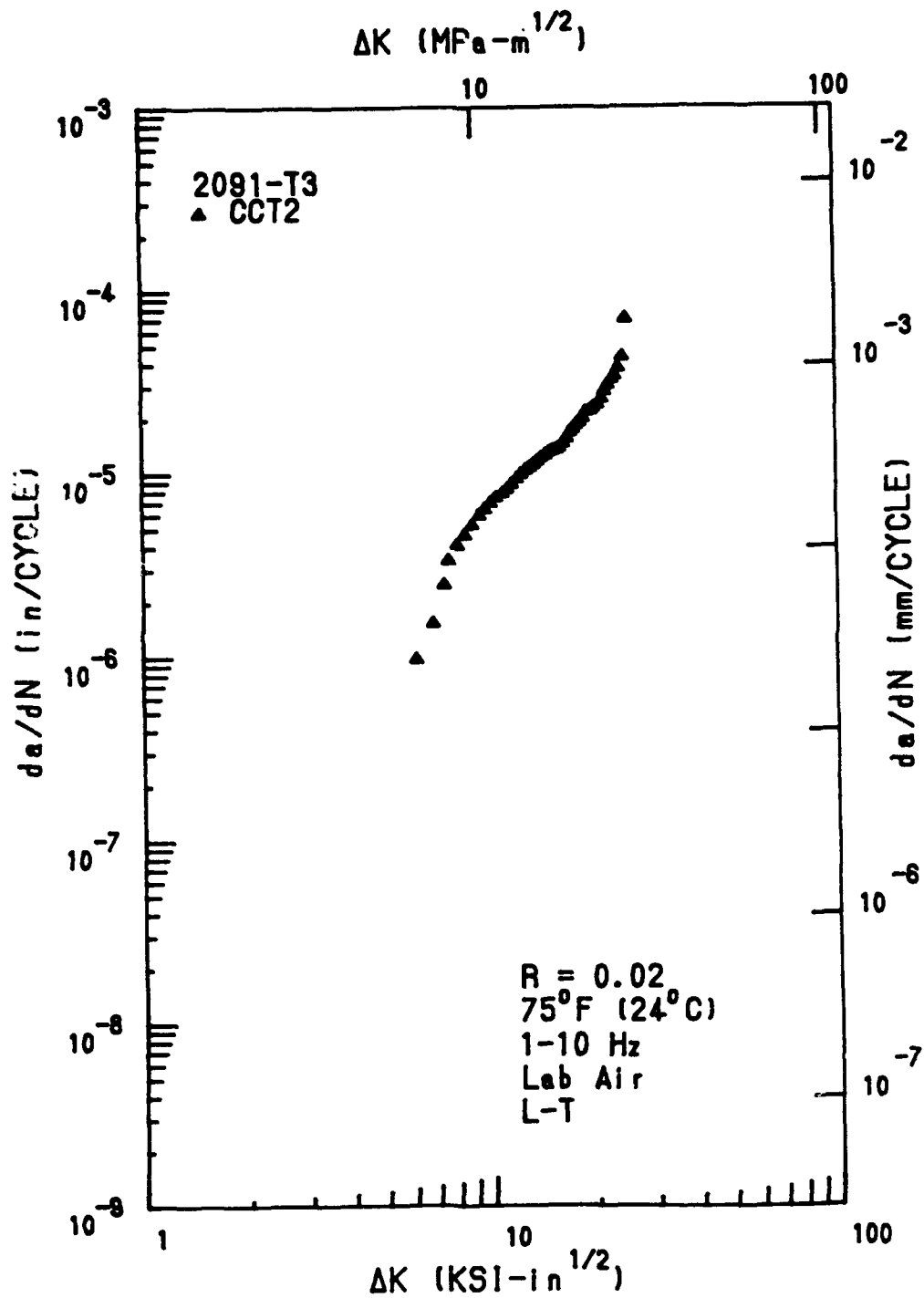


Figure B14 Fatigue Crack Growth Rate Data for Pechinev 2091-T3  
 0.063" Sheet (L-T Orientation). McDonnell Aircraft LA.

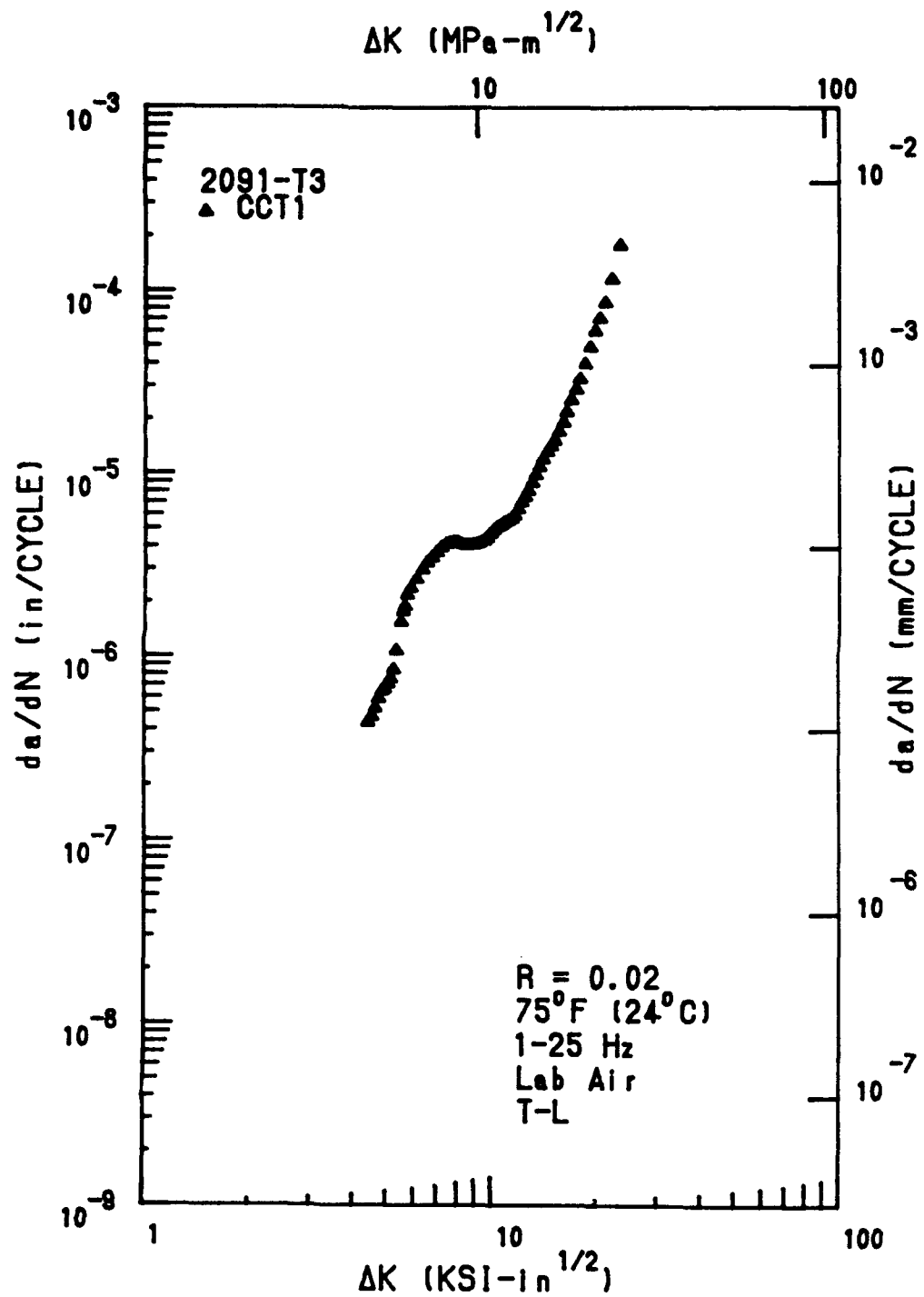


Figure B15 Fatigue Crack Growth Rate Data for Pechiney 2091-T3  
0.063" Sheet (T-L Orientation). McDonnell Aircraft LA.

2091-T8X SHEET  
(0.063"x79"x79")

TABLE B27

## TENSILE RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)
NORTHROP	RT	LONG	62.9	47.5	15.6		11.1
			63.0	47.4	16.5		11.1
			63.1	47.7	18.3		10.5
GRUMMAN	RT	LONG	61.8	47.3	15.5		10.9
			61.8	47.7	16.5		11.2
			62.8	47.3	15.5		11.6
GENERAL DYNAMICS, TEXAS	RT	LONG	65.6	49.7	14.1		
			64.7	49.1	14.1		
		AVERAGE	63.2	48.0	15.8		11.1
		STANDARD DEVIATION	1.3	0.9	1.4		0.4

TABLE B28

## TENSILE RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)
NORTHROP	RT	L TRANS	65.9	47.5	14.3		11.0
			66.0	47.6	13.6		11.4
			66.6	48.0	14.0		11.2
GRUMMAN	RT	L TRANS	64.4	46.3	12.0		11.0
			64.6	46.6	15.0		11.4
			64.8	46.7	14.0		11.5
GENERAL DYNAMICS, TEXAS	RT	L TRANS	67.2	50.2	11.0		
			67.5	50.7	10.4		
		AVERAGE	65.9	48.0	13.0		11.3
		STANDARD DEVIATION	1.2	1.7	1.7		0.2

TABLE B29

## COMPRESSION RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
NORTHROP	RT	LONG	46.8	11.6
			46.7	11.5
			46.9	11.5
GRUMMAN	RT	LONG	45.3	11.6
			47.9	11.5
			46.3	11.5
GENERAL DYNAMICS, TEXAS	RT	LONG	48.8	
			49.7	
		AVERAGE	47.3	11.5
		STANDARD DEVIATION	1.4	0.1

TABLE B30

## COMPRESSION RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
NORTHROP	RT	L TRANS	53.0	11.5
			52.7	11.5
			53.0	11.3
GRUMMAN	RT	L TRANS	51.3	11.2
			51.3	11.4
			52.3	11.7
GENERAL DYNAMICS, TEXAS	RT	L TRANS	53.1	
			53.7	
		AVERAGE	52.5	11.4
		STANDARD DEVIATION	0.9	0.2

**TABLE B31**

**COMPRESSION RESULTS FOR PECHINEY**

**2091-T8X SHEET (0.063" X 79" X 39")**

<b>COMPANY</b>	<b>TEST TEMPERATURE (DEGREES F)</b>	<b>ORIENTATION</b>	<b>COMPRESSIVE YIELD STRENGTH (KSI)</b>	<b>COMPRESSIVE MODULUS (MSI)</b>
<b>GRUMMAN</b>	<b>RT</b>	<b>45</b>	<b>44.6</b>	<b>11.4</b>
			<b>45.5</b>	<b>11.3</b>
			<b>45.2</b>	<b>11.4</b>
		<b>AVERAGE</b>	<b>45.1</b>	<b>11.4</b>
		<b>STANDARD DEVIATION</b>	<b>0.5</b>	<b>0.1</b>

**TABLE B32**  
**SLOTTED SHEAR RESULTS FOR PECHINEY**  
**2091-T8X SHEET (0.063" X 79" X 39")**

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
NORTHROP	LONG	39.4
		35.5
		39.6
GRUMMAN	LONG	38.2
		40.0
		39.1
GENERAL DYNAMICS, TEXAS	LONG	40.9
		42.0
	AVERAGE	39.3
	STANDARD DEVIATION	1.9

**TABLE B33**  
**SLOTTED SHEAR RESULTS FOR PECHINEY**  
**2091-T8X SHEET (0.063" X 79" X 39")**

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
NORTHROP	L TRANS	41.8
		41.9
		41.9
GRUMMAN	L TRANS	41.1
		41.7
		40.7
GENERAL DYNAMICS, TEXAS	L TRANS	38.4
	AVERAGE	41.1
	STANDARD DEVIATION	1.3

TABLE B34

## BEARING RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	e/D	BEARING		BEARING
			ULT.	STR.	YIELD STR.
			(KSI)		(KSI)
NORTHROP	LONG	1.5		94.9	67.6
				94.9	68.3
				94.9	67.2
GRUMMAN	LONG	1.5		91.7	65.5
				91.7	65.4
				91.7	66.2
GENERAL DYNAMICS, TEXAS	LONG	1.5		88.6	75.6
				93.8	78.2
		AVERAGE		92.8	69.3
		STANDARD DEVIATION		2.3	4.9

TABLE B35

## BEARING RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	e/D	BEARING	
			ULT. STR. (KSI)	YIELD STR. (KSI)
NORTHROP	L TRANS	1.5	96.3	67.6
			96.3	67.1
			96.2	68.0
GRUMMAN	L TRANS	1.5	91.9	65.0
			92.4	66.7
			93.1	66.5
GENERAL DYNAMICS, TEXAS	L TRANS	1.5	92.9	78.8
			92.3	78.5
AVERAGE			93.9	69.8
STANDARD DEVIATION			2.0	5.5

TABLE B36

## BEARING RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	e/D	BEARING		BEARING
			ULT.	STR.	YIELD STR.
			(KSI)		(KSI)
NORTHROP	LONG	2.0	117.2		80.0
			118.6		79.8
			117.1		81.5
GRUMMAN	LONG	2.0	116.4		79.2
			116.4		78.7
			116.4		78.6
GENERAL DYNAMICS, TEXAS	LONG	2.0	106.0		88.1
			117.0		92.2
AVERAGE			115.6		82.3
STANDARD DEVIATION			4.0		5.1

TABLE B37

## BEARING RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	e/D	BEARING	
			ULT. STR. (KSI)	YIELD STR. (KSI)
NORTHROP	L TRANS	2.0	120.4	81.6
			120.1	84.0
			118.6	82.0
GRUMMAN	L TRANS	2.0	121.8	83.2
			120.0	81.8
			117.6	80.8
GENERAL DYNAMICS, TEXAS	L TRANS	2.0	114.0	95.8
			105.0	93.6
AVERAGE			117.2	85.4
STANDARD DEVIATION			5.5	5.9

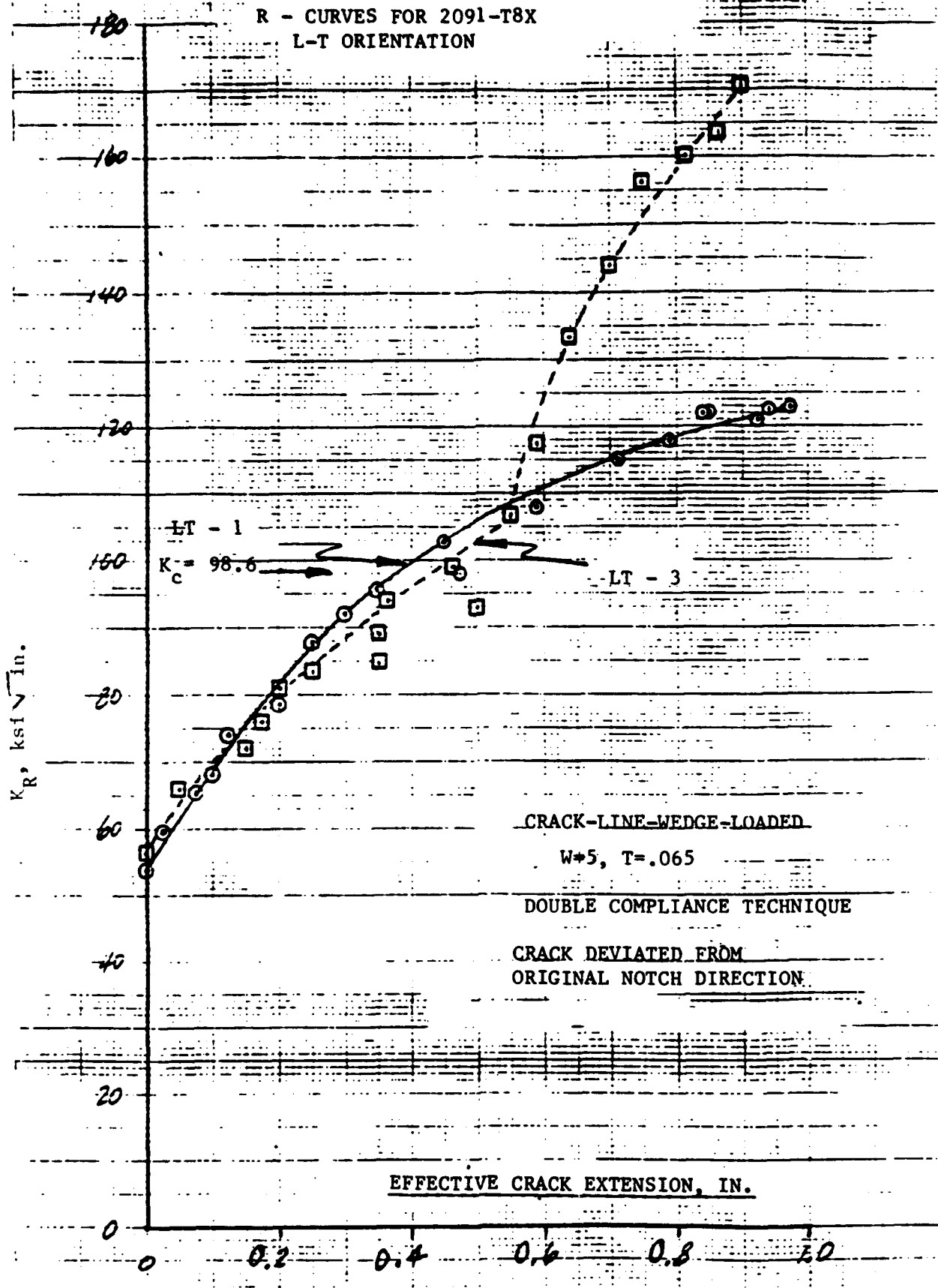


Figure B16 R-Curve Results for 2091-T8X 0.063" Sheet (L-T). Grumman.

# R-CURVES FOR 2091-T8X

T-L ORIENTATION

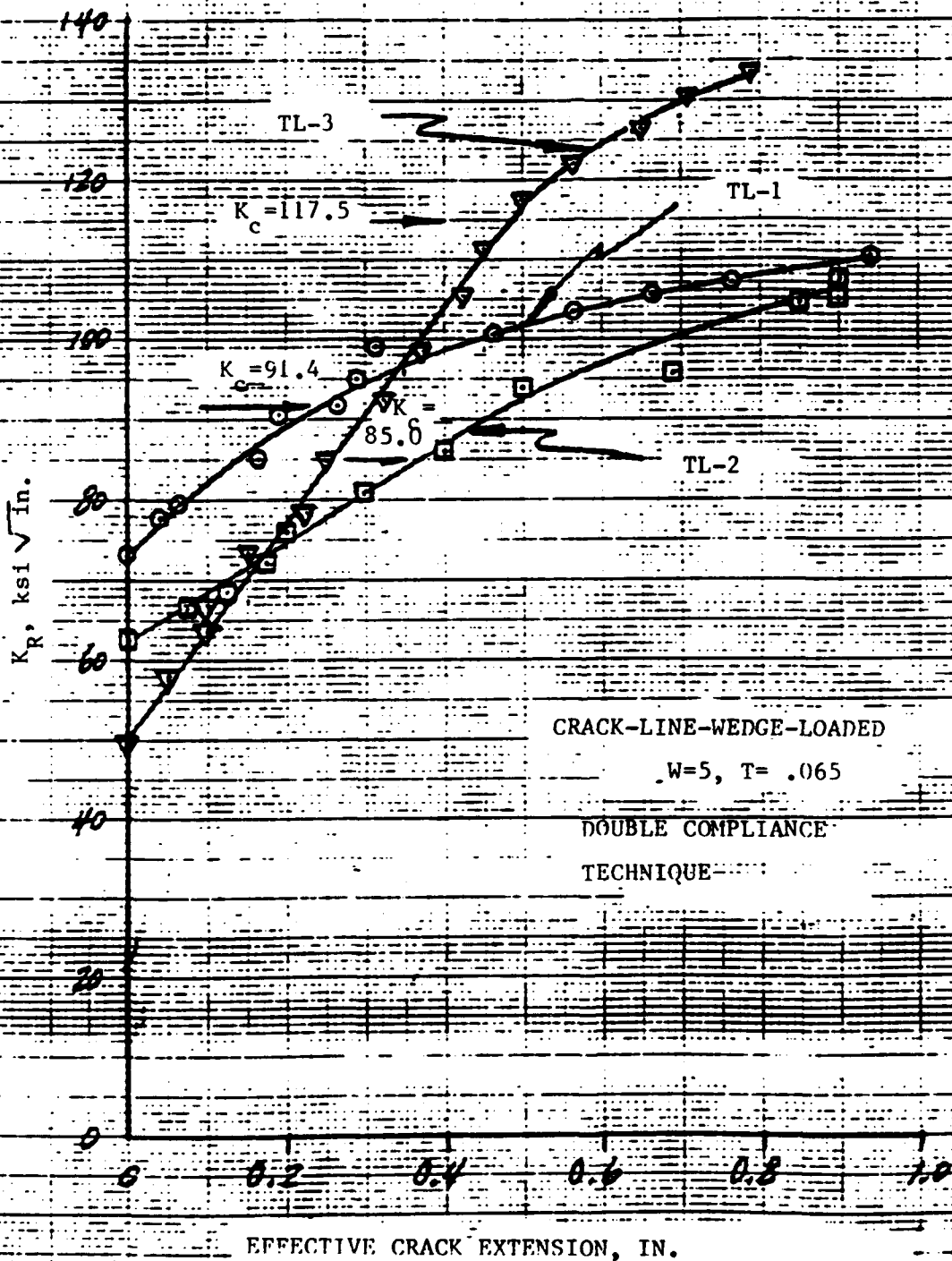


Figure B17 R-Curve Results for 2091-T8X 0.063" Sheet (T-L). Grumman.

**TABLE B38**

**General Dynamics, Texas**

**Pechiney 2091-T81 Sheet  
(0.063" X 79" X 39")  
Average Results of R-Curve Tests**

**$K_{R25}, \text{ksi-in}^{\frac{1}{2}}$**

**L-T            91.2**

**T-L            81.4**

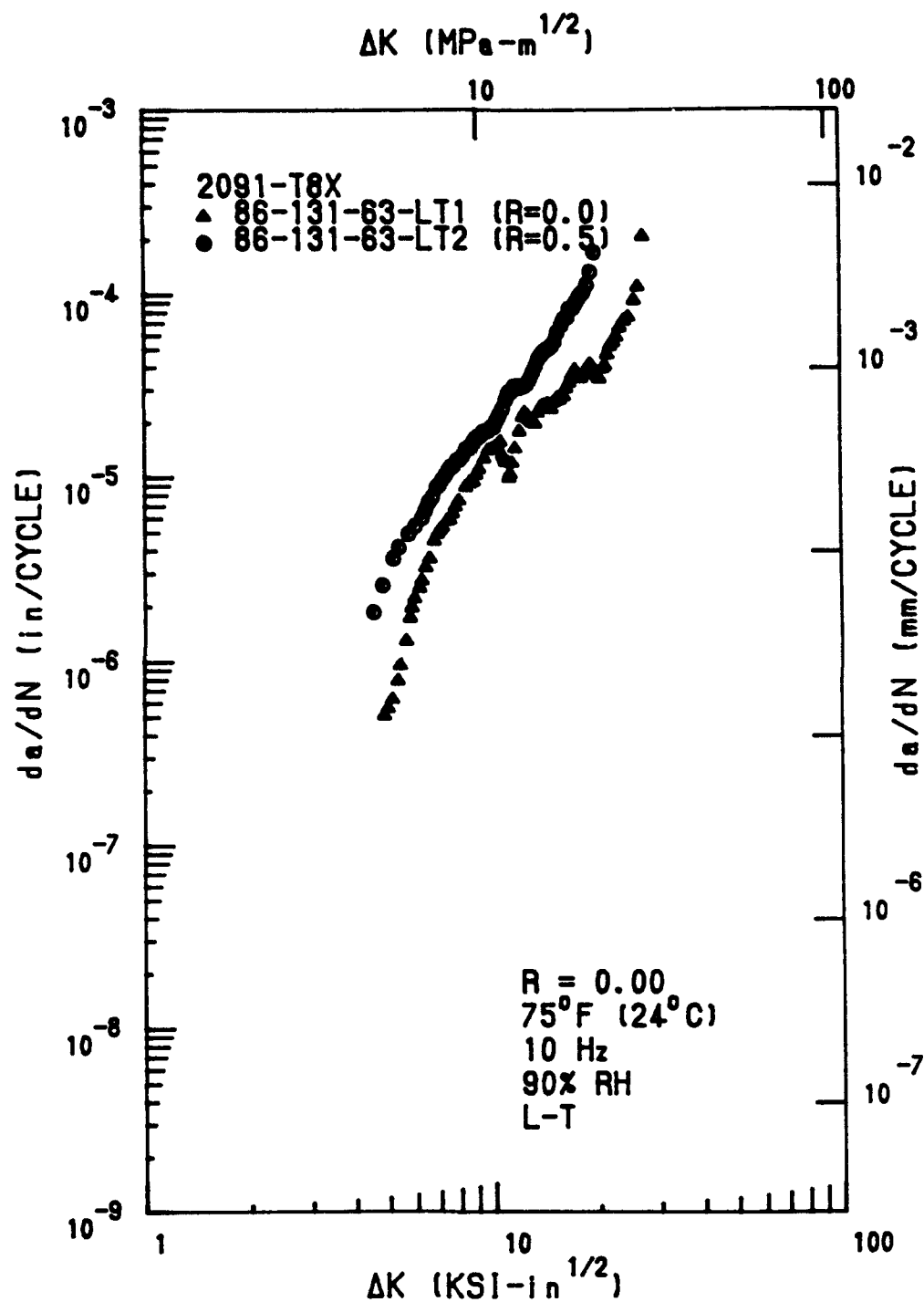


Figure B18 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X  
 0.063" Sheet (L-T Orientation). Grumman.

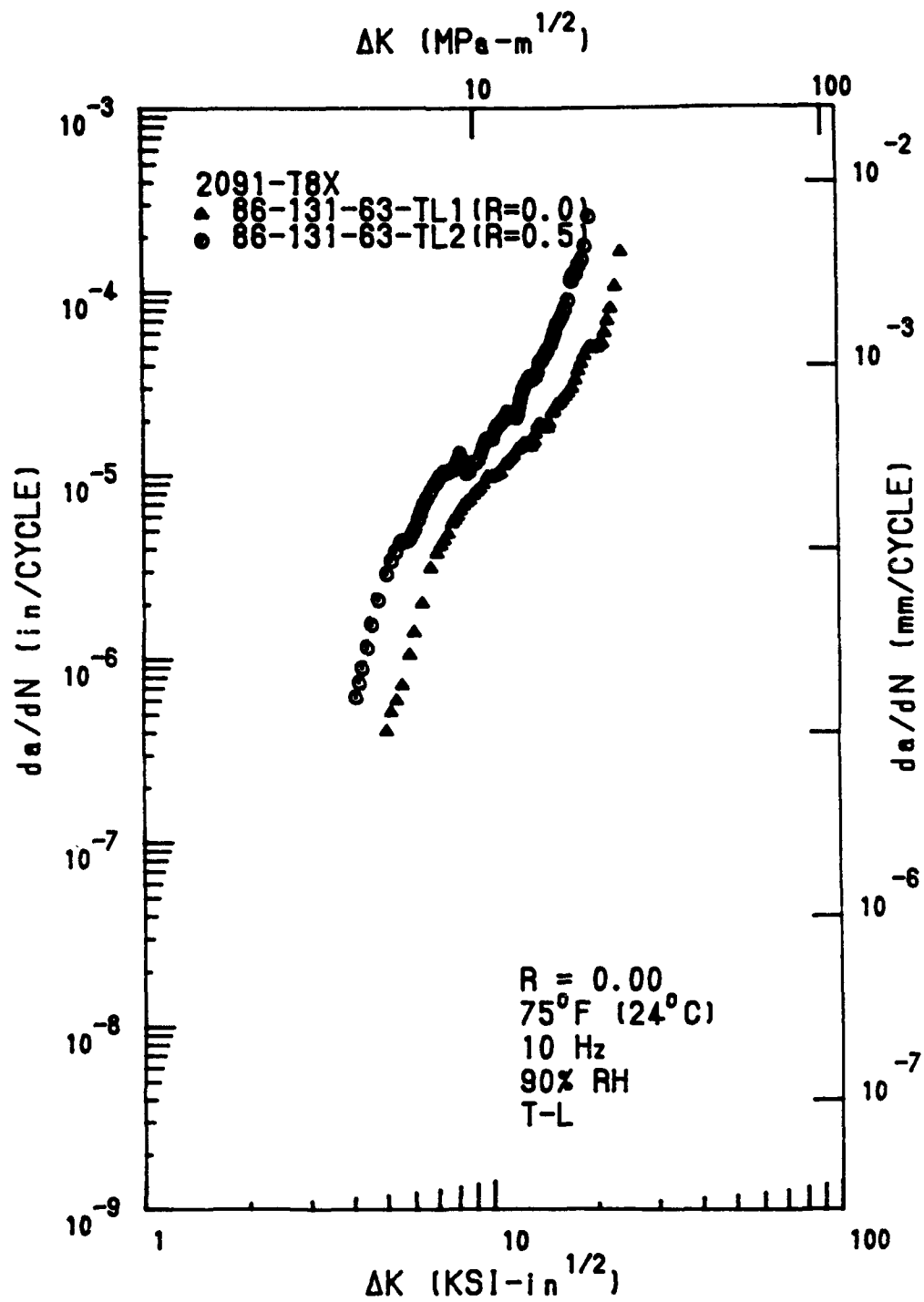


Figure B19 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X  
 0.063" Sheet (T-L Orientation). Gruman.

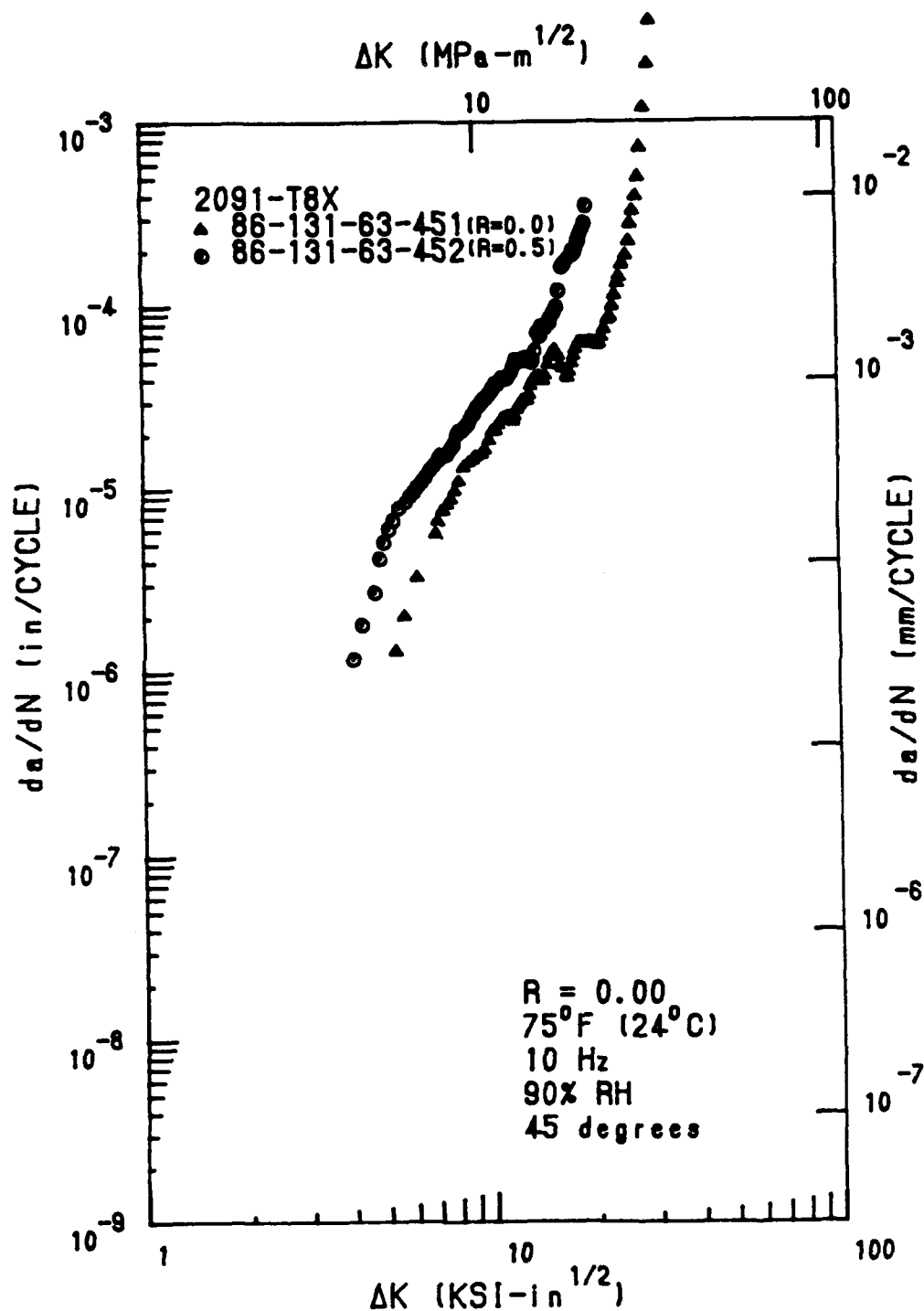


Figure B20 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X  
0.063" Sheet (45° Orientation). Gruman.

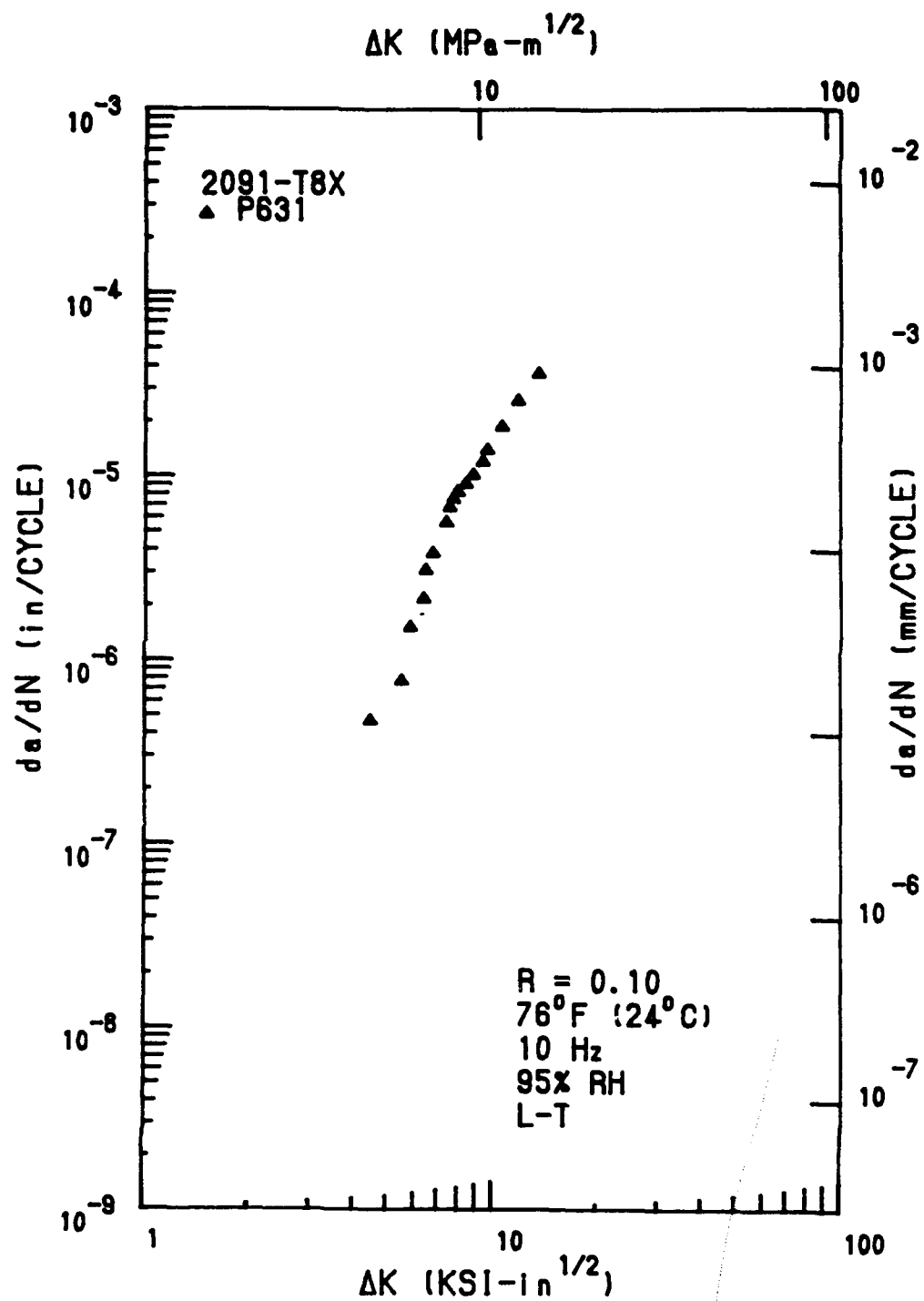


Figure B21 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X  
0.063" Sheet (L-T Orientation). Northrop.

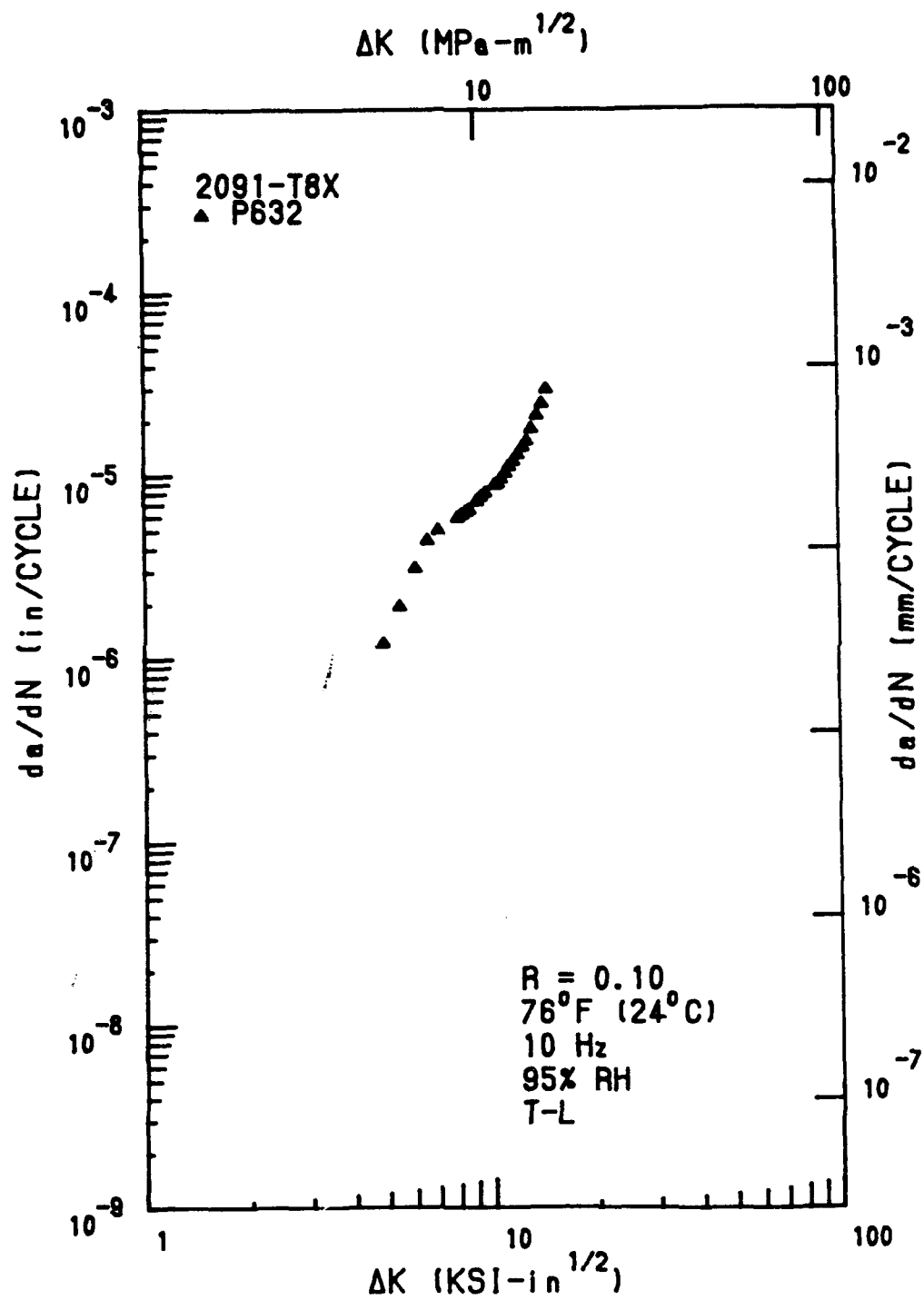
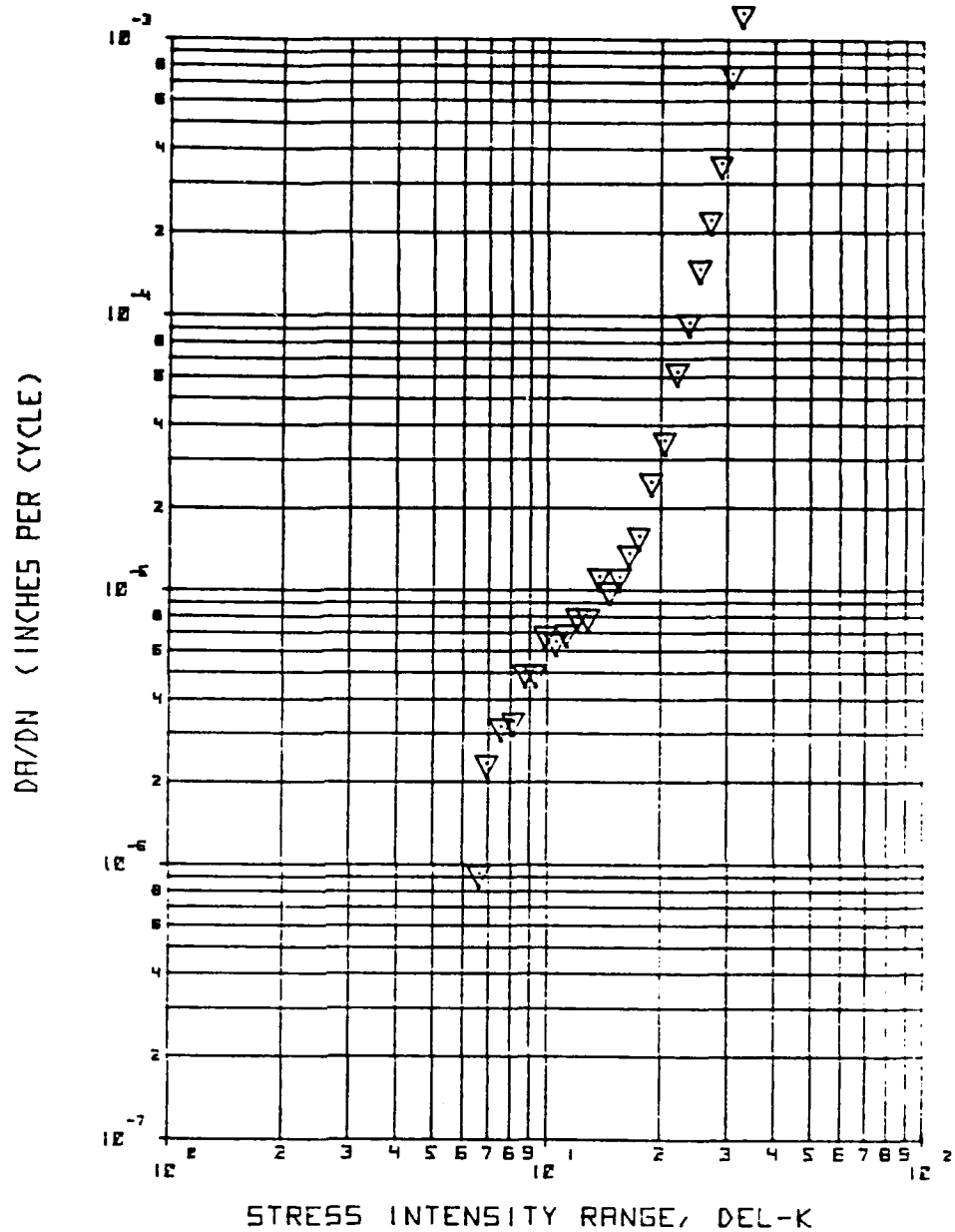
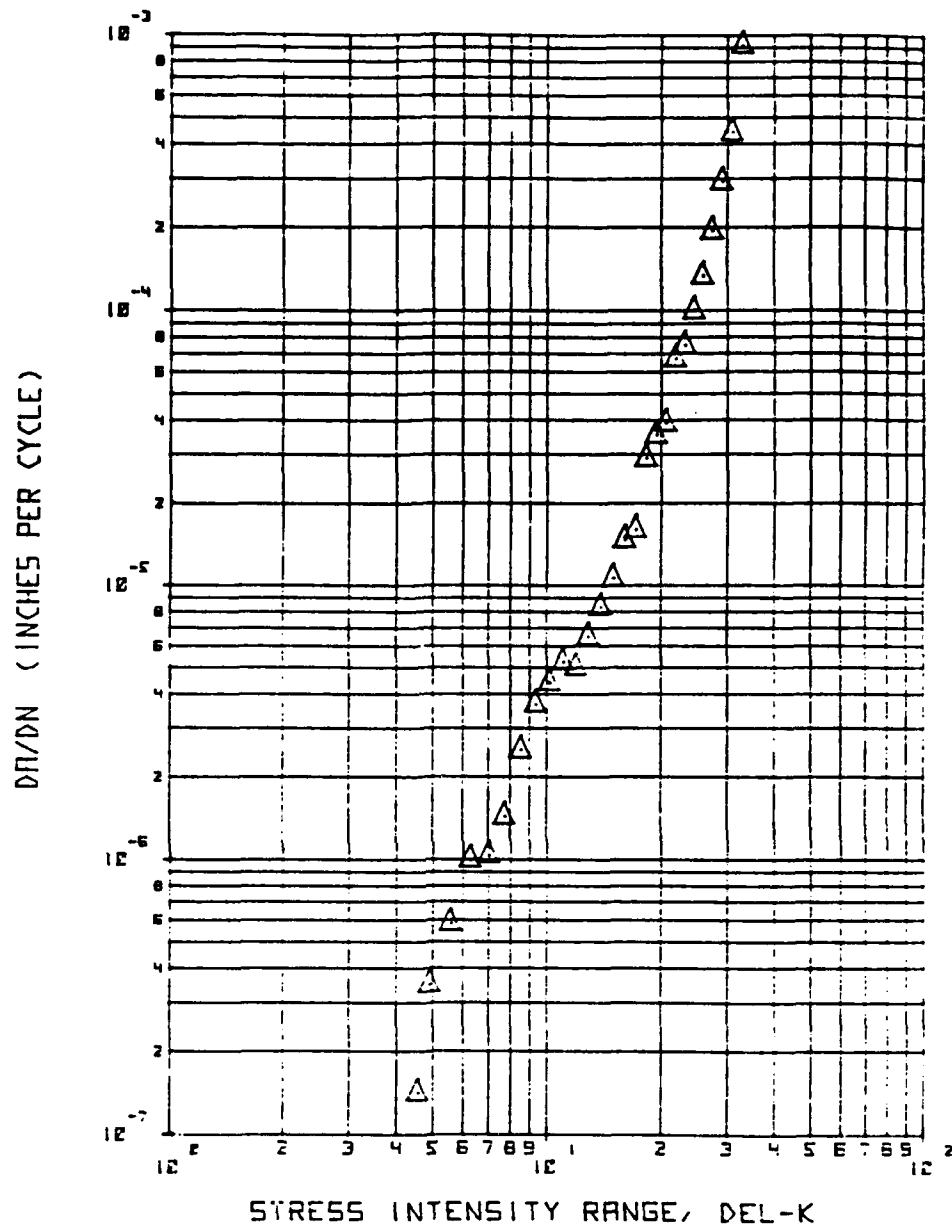


Figure B22 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X  
0.063" Sheet (T-L Orientation). Northrop.





Material: 2091-T81 Sheet  
 Age: 335°F - 32 hrs  
 Environment: Lab air, Room temperature  
 Orientation: T-L  
 Stress Ratio: 0.1  
 Frequency: 5 Hz

Figure B24 K-increasing Constant Amplitude Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.063" Sheet (T-L). General Dynamics, TX.

**APPENDIX C**  
**PECHINEY**  
**2091-T6 PRECISION FORGING**

**INTRODUCTION**

The Pechiney 2091-T6 precision forgings were received the third quarter of 1986. Five participants tested this material; Boeing Commercial Airplane Company, General Dynamics Fort Worth Division, Lockheed Aeronautical Systems Company, Martin Marietta Manned Space Systems and Northrop Corporation. Forging Dimensions are shown in Figure C1.

**TESTING**

Basic mechanical properties (tension, compression, bearing, etc.) were tested according to ASTM standards, unless otherwise specified.

Constant amplitude fatigue crack growth tests were conducted according to ASTM E647 Standard. The growth rate  $a-N$  data that was generated by the participant, Northrop Corporation, was reduced using a seven-point incremental polynomial (parabola) to sets of seven successive data points. The data are also checked against size requirements per ASTM E647, Section 7.2.

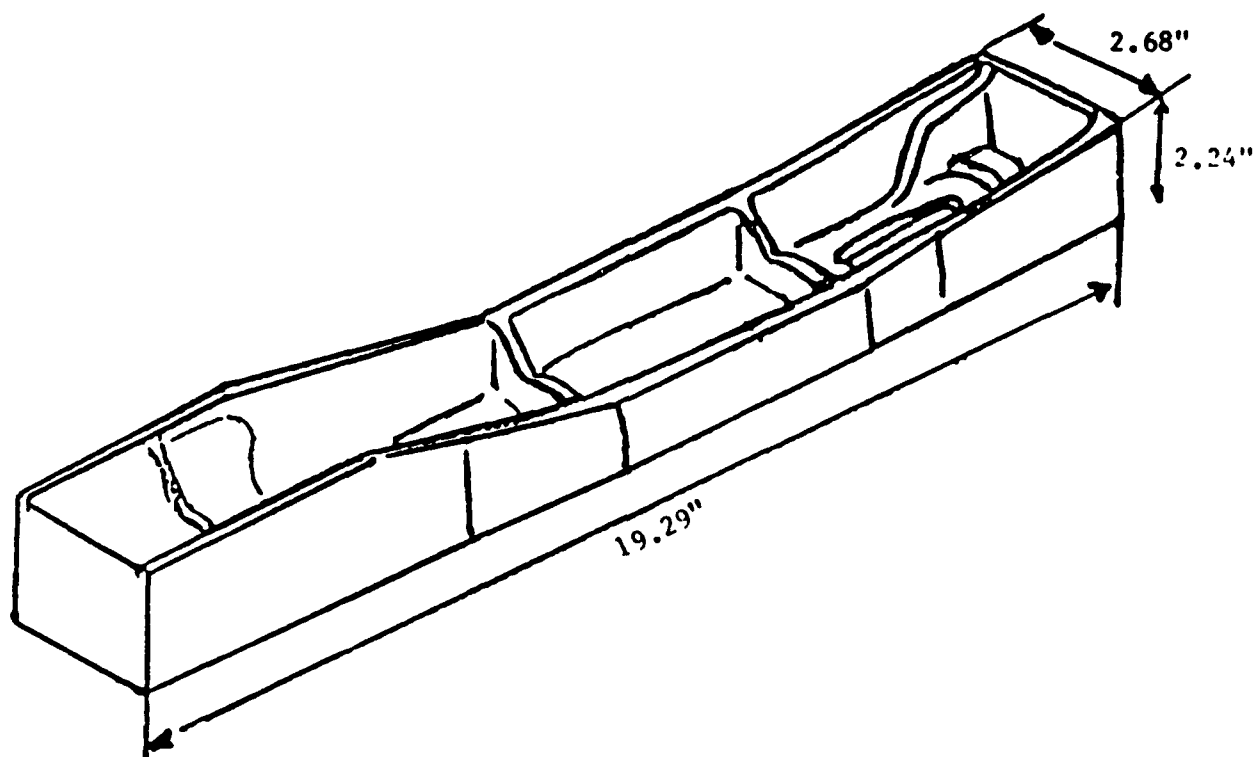


Figure C1 2091-T6 Precision Die Forging Dimensions.

TABLE C1  
TENSILE RESULTS AT t/2 LOCATION FOR  
PECHINEY 2091-T6 FORGINGS

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)	COMMENT
BOEING	RT	LONG	73.6	65.3	4.0			
			77.9	66.5	5.0			
			82.2	72.3	8.0			
NORTHROP	RT	LONG	81.3	69.4	10.0	9.0	11.2	(1), (2)
			82.8	72.1	9.0	7.5	11.4	(2)
			83.1	73.0	8.0	6.4	11.4	(2)
			85.9	76.7	8.0	7.5	11.1	(2)
			80.2	69.8	8.0	7.1	11.5	(2)
			85.0	75.5	8.0	7.4	11.3	(2)
			81.7	72.7	5.0	4.5	11.2	(3)
			81.6	71.8	7.0	5.7	11.3	(3)
			67.1	58.4	3.0	2.0	11.2	(4)
		68.0	56.6	4.0	3.3	11.2	(4)	
GENERAL DYNAMICS, TEXAS	RT	LONG	84.4	73.5	6.7			
			84.0	73.0	6.8			
LOCKHEED, GEORGIA	RT	LONG	83.9	72.7	9.0		12.6	
			80.1	68.4	8.0		12.5	
			80.9	68.9	9.0		11.5	
			83.9	72.4	8.0		11.1	
			83.7	72.7	9.0		11.8	
MARTIN MARIETTA, LOUISIANA	RT	LONG	74.6	66.4	2.0	6.0	11.4	
			81.3	68.7	5.0	10.0	11.8	
			77.9	63.2	5.0	10.0	11.2	
AVERAGE			80.2	69.7	6.8	6.6	11.5	
STANDARD DEVIATION			5.0	5.0	2.2	2.4	0.5	

- (1): INDICATES THAT THE SPECIMEN FAILED OUTSIDE THE GAGE MARKS  
 (2): SPECIMEN REMOVED FROM THE FORGING BASE  
 (3): SPECIMEN REMOVED FROM THE FORGING SIDE WALL  
 (4): SPECIMEN REMOVED FROM THE FORGING END WALL

TABLE C2  
TENSILE RESULTS AT 1/2 LOCATION FOR  
PECHINEY 2091-T6 FORGINGS

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)	COMMENT		
NORTHROP	RT	L TRANS	66.4				11.2	(1), (2)		
			78.6	70.9	5.0		11.4	(2)		
			63.8				11.3	(1), (2)		
			75.0	68.3	3.0		11.2	(1), (2)		
			60.6		1.0		11.2	(1), (2)		
			71.5	66.0	2.0		10.8	(1), (2)		
			69.2	63.2	2.0		11.3	(4)		
			66.1	58.7	2.0		11.1	(4)		
			AVERAGE			68.9	65.4	2.5		11.2
			STANDARD DEVIATION			5.9	4.7	1.4		0.2

- (1): INDICATES THAT THE SPECIMEN FAILED OUTSIDE THE GAGE MARKS  
 (2): SPECIMEN REMOVED FROM THE FORGING BASE  
 (3): SPECIMEN REMOVED FROM THE FORGING SIDE WALL  
 (4): SPECIMEN REMOVED FROM THE FORGING END WALL

TABLE C3  
TENSILE RESULTS AT t/2 LOCATION FOR  
PECHINEY 2091-T6 FORGINGS

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)	COMMENT
LOCKHEED, GEORGIA	RT	S TRANS	68.7		6.0			
			72.2		6.0			
			66.6		6.0			
			70.9		6.0			
			72.1		6.0			
		AVERAGE	70.1		6.0			
		STANDARD DEVIATION	2.4		0.0			

TABLE C4  
COMPRESSION RESULTS AT 1/2 LOCATION FOR  
PECHINEY 2091-T6 FORGINGS

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
BOEING	RT	LONG	68.6	
			72.4	
			70.4	
NORTHROP	RT	LONG	67.3	11.7
			73.8	11.6
			75.4	11.8
LOCKHEED, GEORGIA	RT	LONG	67.0	
			62.0	
			64.7	
			62.7	
			65.6	
GENERAL DYNAMICS, TEXAS	RT	LONG	57.7	
MARTIN MARLETTA, LOUISIANA	RT	LONG	73.4	12.2
			64.3	12.1
AVERAGE			67.5	11.9
STANDARD DEVIATION			5.1	0.3

NOTE: NORTHROP SPECIMENS TAKEN FROM FORGING SIDE WALL.

TABLE C5

COMPRESSION RESULTS AT t/2 LOCATION FOR  
PECHINEY 2091-T6 FORGINGS

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MARTIN	RT	L TRANS	61.7	12.0
MARIETTA.			60.2	12.0
LOUISIANA				
AVERAGE			61.0	12.0
STANDARD DEVIATION			1.1	0.0

TABLE C6

AMSLER DOUBLE SHEAR RESULTS FOR  
PECHINEY 2091-T6 FORGINGS

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
-----		
NORTHROP	L-S	38.6
		39.5
		38.9
LOCKHEED. GEORGIA	L-S	38.7
		40.4
		39.8
AVERAGE		39.3
STANDARD DEVIATION		0.7

NOTE: NORTHROP SPECIMENS TAKEN FROM FORGING SIDE WALL.

TABLE C7  
 AMSLER DOUBLE SHEAR RESULTS FOR  
 PECHINEY 2091-T6 FORGINGS

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
<hr/>		
NORTHROP	T-S	38.0
		37.1
		35.8
LOCKHEED. GEORGIA	T-S	39.0
		42.4
		38.3
	AVERAGE	38.4
	STANDARD DEVIATION	2.2

NOTE: NORTHROP SPECIMENS TAKEN FROM FORGING END WALL.

TABLE C8  
 SLOTTED SHEAR RESULTS FOR PECHINEY  
 2091-T6 FORGINGS

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
<hr/>		
BOEING	LONG	43.3
		44.9
		43.1
	AVERAGE	43.8
	STANDARD DEVIATION	1.0

TABLE C9  
BEARING RESULTS FOR PECHINEY  
2091-T6 FORGINGS

COMPANY	ORIENTATION	e/D	BEARING	
			ULT. STR. (KSI)	YIELD STR. (KSI)
BOEING	LONG	1.5	73.9	65.6
			82.7	65.9
			85.5	72.3
NORTHROP	LONG	1.5	103.8	87.7
			95.0	81.8
			99.8	82.2
LOCKHEED, GEORGIA	LONG	1.5	95.3	84.7
			99.0	85.7
			102.2	86.3
AVERAGE			93.0	79.1
STANDARD DEVIATION			10.1	8.8

NOTE: NORTHROP SPECIMENS REMOVED FROM FORGING SIDE WALL.

TABLE C10  
BEARING RESULTS FOR PECHINEY  
2091-T6 FORGINGS

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR. (KSI)	YIELD	STR. (KSI)
BOEING	LONG	2.0		142.3		105.3
				144.9		112.9
				142.0		105.7
NORTHROP	LONG	2.0		134.8		104.3
				139.6		105.1
				136.4		105.0
GENERAL DYNAMICS, TEXAS	LONG	2.0		129.0		116.0
LOCKHEED, GEORGIA	LONG	2.0		129.2		108.6
				128.1		105.1
				132.8		109.2
AVERAGE				135.9		107.7
STANDARD DEVIATION				6.1		4.0

NOTE: NORTHROP SPECIMENS REMOVED FROM FORGING SIDE WALL.

TABLE C11

## BEARING RESULTS FOR PECHINEY

## 2091-T6 FORGINGS

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR. (KSI)	YIELD	STR. (KSI)
GENERAL DYNAMICS, TEXAS	L TRANS	2.0		128.0		87.2
AVERAGE				128.0		87.2
STANDARD DEVIATION						

TABLE C12

FRACTURE TOUGHNESS RESULTS FOR  
PECHINEY 2091-T6 FORGINGS

COMPANY	ORIENTATION	K <sub>IC</sub>		K <sub>q</sub>	COMMENT
		(KSI IN <sup>-0.5</sup> )	(KSI IN <sup>-0.5</sup> )		
NORTHROP	L-T			29.1	(1), (3), (4)
				22.2	(2), (3), (4)
MARTIN MARIETTA, LOUISIANA	L-T			25.8	(4), (5)
				27.6	(4), (5)
	AVERAGE			26.2	
	STANDARD DEVIATION			3.0	

- (1): W=1.0  
 (2): W=0.8  
 (3): SPECIMEN REMOVED FROM FORGING BASE  
 (4): INVALID  
 (5): VIOLATES SPECIMEN THICKNESS REQUIREMENTS

TABLE C13  
FRACTURE TOUGHNESS RESULTS FOR  
PECHINEY 2091-T6 FORGINGS

COMPANY	ORIENTATION	KIC	Kq	COMMENT
		(KSI IN <sup>-0.5</sup> )	(KSI IN <sup>-0.5</sup> )	
NORTHROP	T-L		24.1	(1), (3), (4)
			27.4	(2), (3), (4)
GENERAL DYNAMICS, TEXAS	T-L		25.9	(5)
			20.4	(5)
MARTIN MARIETTA, LOUISIANA	T-L		22.0	(4), (7)
			25.3	(4), (7)
	AVERAGE		24.2	
	STANDARD DEVIATION		2.6	

- (1): W=1.0  
 (2): W=0.8  
 (3): SPECIMEN REMOVED FROM FORGING BASE  
 (4): INVALID  
 (5): INVALID DUE TO - INSUFFICIENT THICKNESS,  $P_{max}/P_q > 1.10$ ,  
 AND MINIMUM SURFACE CRACK LENGTH < 90%  
 (6): INVALID DUE TO -  $P_{max}/P_q > 1.10$ , MINIMUM SURFACE CRACK LENGTH  
 < 90%, AND CRACK CURVATURE > 5%  
 (7): VIOLATED SPECIMEN THICKNESS REQUIREMENTS

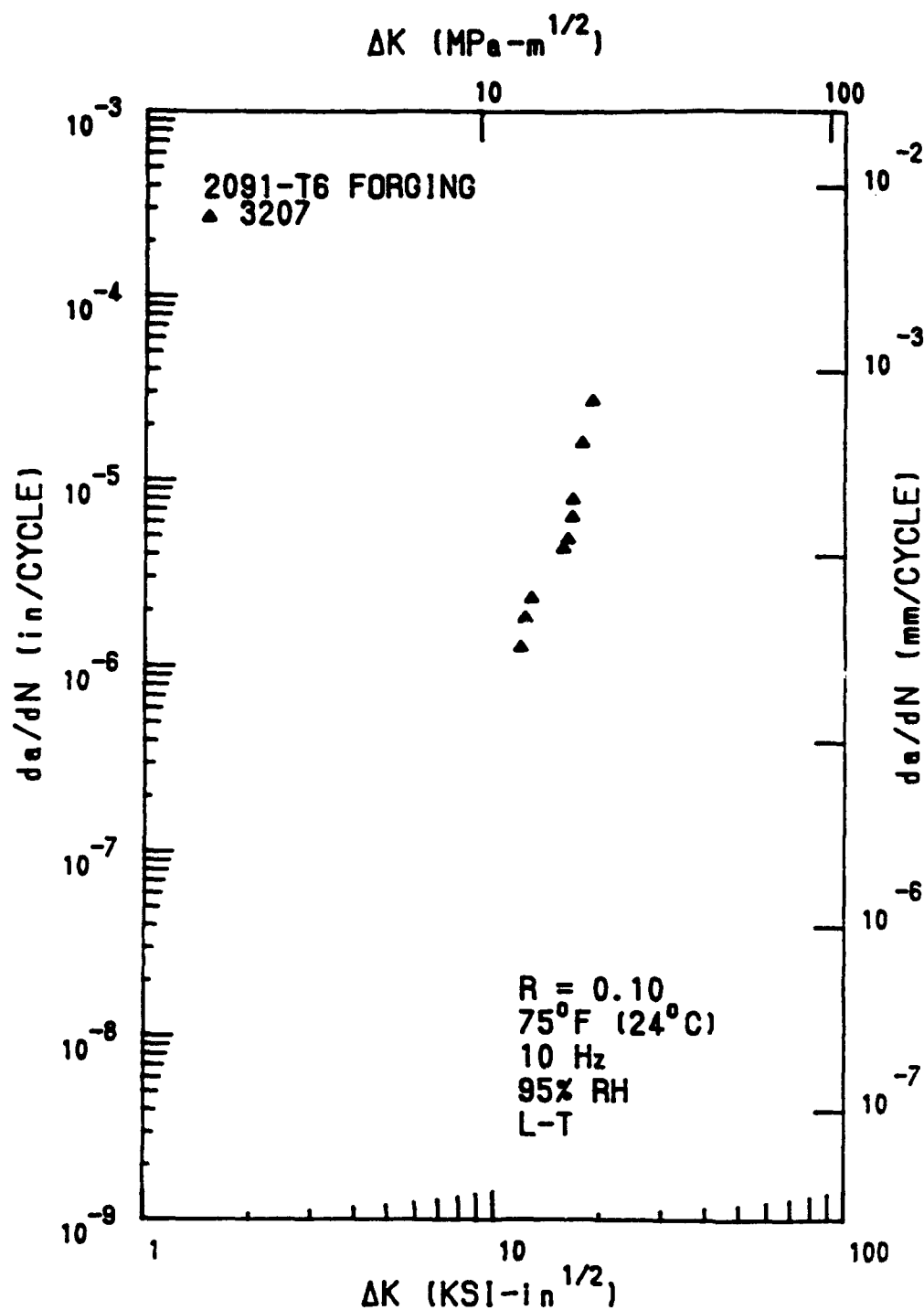


Figure C2 Fatigue Crack Growth Rate Data for Pechiney 2091-T6 Forging (L-T Orientation). Northrop.

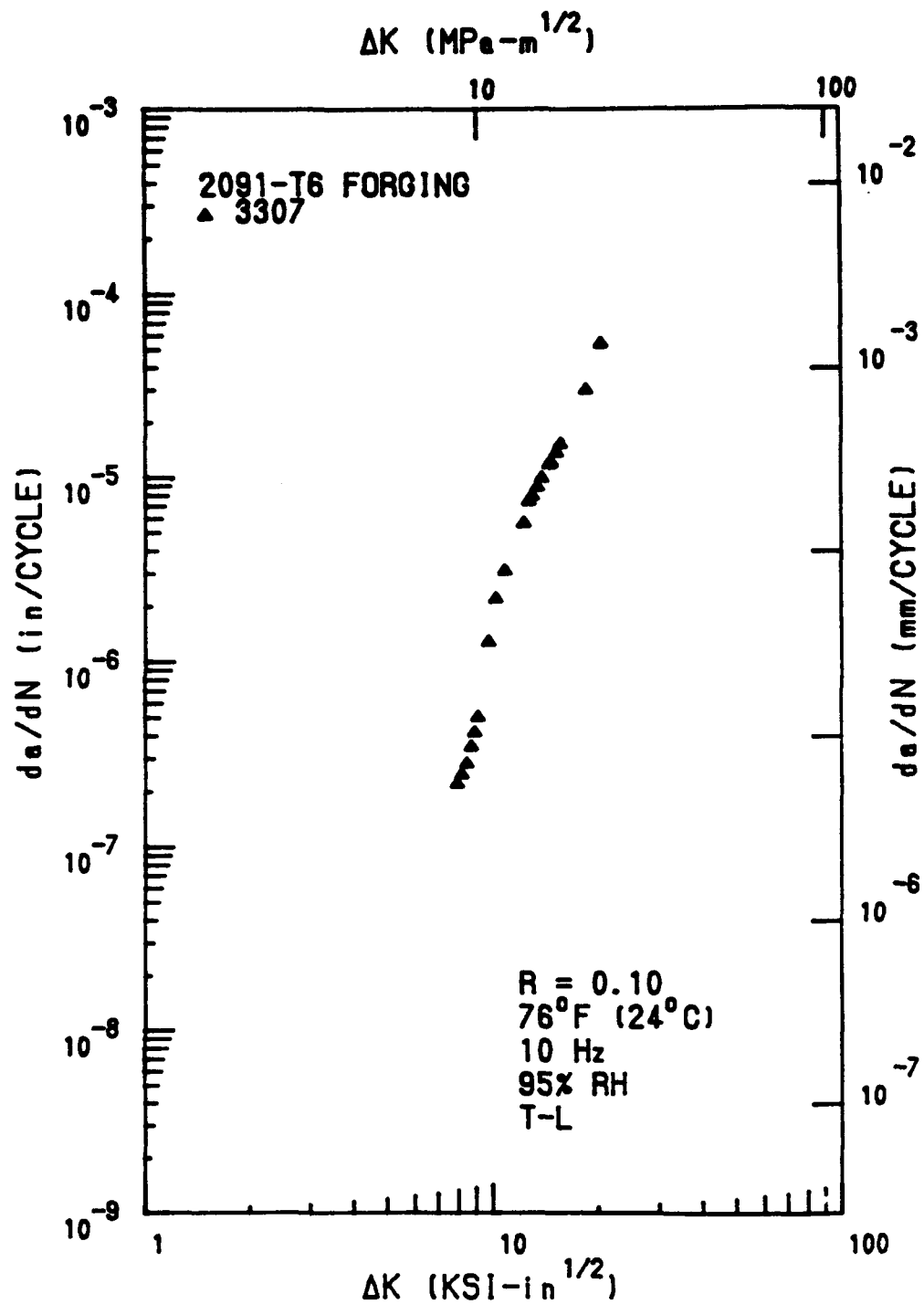


Figure C3 Fatigue Crack Growth Rate Data for Pechiney 2091-T6 Forging (T-L Orientation). Northrop.

## **APPENDIX D**

### **PECHINEY**

#### **8090-T651 T-EXTRUSION**

##### **INTRODUCTION**

The Pechiney 8090-T651 T-Extrusions were received the fourth quarter of 1986. Dimensions of the T-Extrusion are 0.19" x 2.5" x 3.0" x 79". Four participants tested this material; Boeing Commercial Airplane Company WA, General Dynamics Fort Worth Division, LTV Aircraft Products Group TX, and the Navy (Naval Air Development Center).

##### **TESTING**

Basic mechanical properties (tension, compression, bearing, etc.) were tested according to ASTM standards, unless otherwise specified.

TABLE D1

## TENSILE RESULTS FOR PECHINEY

8090-T651 T-EXTRUSION (0.19" X 2.5" X 3" X 79")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
BOEING	RT	LONG	77.4	66.9	8.0		
			77.5	67.0	8.0		
			77.4	67.0	8.0		
GENERAL DYNAMICS, TEXAS	RT	LONG	81.0	71.5	5.9		
			77.1	68.3	2.9		
			80.3	70.5	5.7		
			80.7	70.9	4.9		
NADC	RT	LONG	76.0	66.9	3.0		10.4
			81.2	72.4	3.0		11.5
			80.7	71.3	3.0		10.0
			82.2	72.4	3.0		9.5
LTV	RT	LONG	78.5	68.9	6.1		11.6
			77.4	68.5	7.2		11.6
			78.5	69.2	6.9		11.6
AVERAGE			79.0	69.4	5.4		10.9
STANDARD DEVIATION			2.0	2.1	2.1		0.9

TABLE D2

## TENSILE RESULTS FOR PECHINEY

8090-T651 T-EXTRUSION (0.19" X 2.5" X 3" X 79")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
GENERAL DYNAMICS, TEXAS	RT	L TRANS	78.4	69.5	4.4		
			78.2	69.6	4.5		
		AVERAGE	78.3	69.6	4.5		
		STANDARD DEVIATION	0.1	0.1	0.1		

TABLE D3

COMPRESSION RESULTS FOR PECHINEY

8090-T651 T-EXTRUSION (0.19" X 2.5" X 3" X 79")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
BOEING	RT	LONG	68.0	
			67.1	
			67.7	
		AVERAGE	67.6	
		STANDARD DEVIATION	0.5	

**TABLE D4**

**SLOTTED SHEAR RESULTS FOR PECHINEY**

**8090-T651 T-EXTRUSION (0.19" X 2.5" X 3" X 79")**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<hr/>		
<b>BOEING</b>	<b>LONG</b>	<b>42.5</b>
		<b>42.5</b>
		<b>42.5</b>
	<b>AVERAGE</b>	<b>42.5</b>
	<b>STANDARD DEVIATION</b>	<b>0.0</b>

**TABLE D5**

**SLOTTED SHEAR RESULTS FOR PECHINEY**

**8090-T651 T-EXTRUSION (0.19" X 2.5" X 3" X 79")**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<hr/>		
<b>GENERAL DYNAMICS, TEXAS</b>	<b>L TRANS</b>	<b>41.7</b>
		<b>41.2</b>
	<b>AVERAGE</b>	<b>41.5</b>
	<b>STANDARD DEVIATION</b>	<b>0.4</b>

**TABLE D6****IOSIPESCU SHEAR RESULTS FOR PECHINEY****8090-T651 T-EXTRUSION (0.19" X 2.5" X 3" X 79")**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<hr/>		
<b>LTV</b>	<b>LONG</b>	<b>41.4</b>
		<b>40.6</b>
		<b>42.5</b>
	<b>AVERAGE</b>	<b>41.5</b>
	<b>STANDARD DEVIATION</b>	<b>1.0</b>

**TABLE D7****IOSIPESCU SHEAR RESULTS FOR PECHINEY****8090-T651 T-EXTRUSION (0.19" X 2.5" X 3" X 79")**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<hr/>		
<b>LTV</b>	<b>L TRANS</b>	<b>39.5</b>
		<b>40.4</b>
		<b>39.3</b>
	<b>AVERAGE</b>	<b>39.7</b>
	<b>STANDARD DEVIATION</b>	<b>0.6</b>

**TABLE D8**

**BEARING RESULTS FOR PECHINEY**

**8090-T651 T-EXTRUSION (0.19" X 2.5 X 3" X 79")**

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
BOEING	LONG	1.5		103.4		90.2
				106.5		94.6 *
				107.6		95.5 *
GENERAL DYNAMICS, TEXAS	LONG	1.5		106.0		94.3
				104.0		91.2
LTV	LONG	1.5		105.5		97.4
				107.0		96.2
				106.2		93.3
AVERAGE				105.8		94.1
STANDARD DEVIATION				1.4		2.4

(\*): INDICATES SHEAR TEAR OUT FAILURE

TABLE D9

## BEARING RESULTS FOR PECHINEY

8090-T651 T-EXTRUSION (0.19" X 2.5" X 3" X 79")

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
BOEING	LONG	2.0		131.8		105.1 *
				138.6		113.1 *
				135.2		111.4 *
GENERAL DYNAMICS, TEXAS	LONG	2.0		116.0		106.0
				135.0		107.0
LTV	LONG	2.0		135.6		116.4
				136.0		
				133.6		111.2
AVERAGE				132.7		110.0
STANDARD DEVIATION				7.0		4.1

(\*): INDICATES SHEAR-TENSION FAILURE

TABLE D10

FATIGUE RESULTS WITH R=0.1 AND Kt=2.8 FOR  
PECHINEY 8090-T651 T-EXTRUSION (0.19" X 2.5" X 3" X 79")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
LTV	LONG	22.0	54,800
		22.0	58,700
		21.2	83,700
		19.6	213,900
		19.5	78,800
		19.5	176,700
		17.3	219,100
		16.5	212,300
		16.0	300,200
		15.0	341,600
		14.9	1,000,000 *

(\*): INDICATES A RUN-OUT TEST

# Pechiney 8090-T651 T-Extrusion (0.19" X 2.5" X 3" X 79")

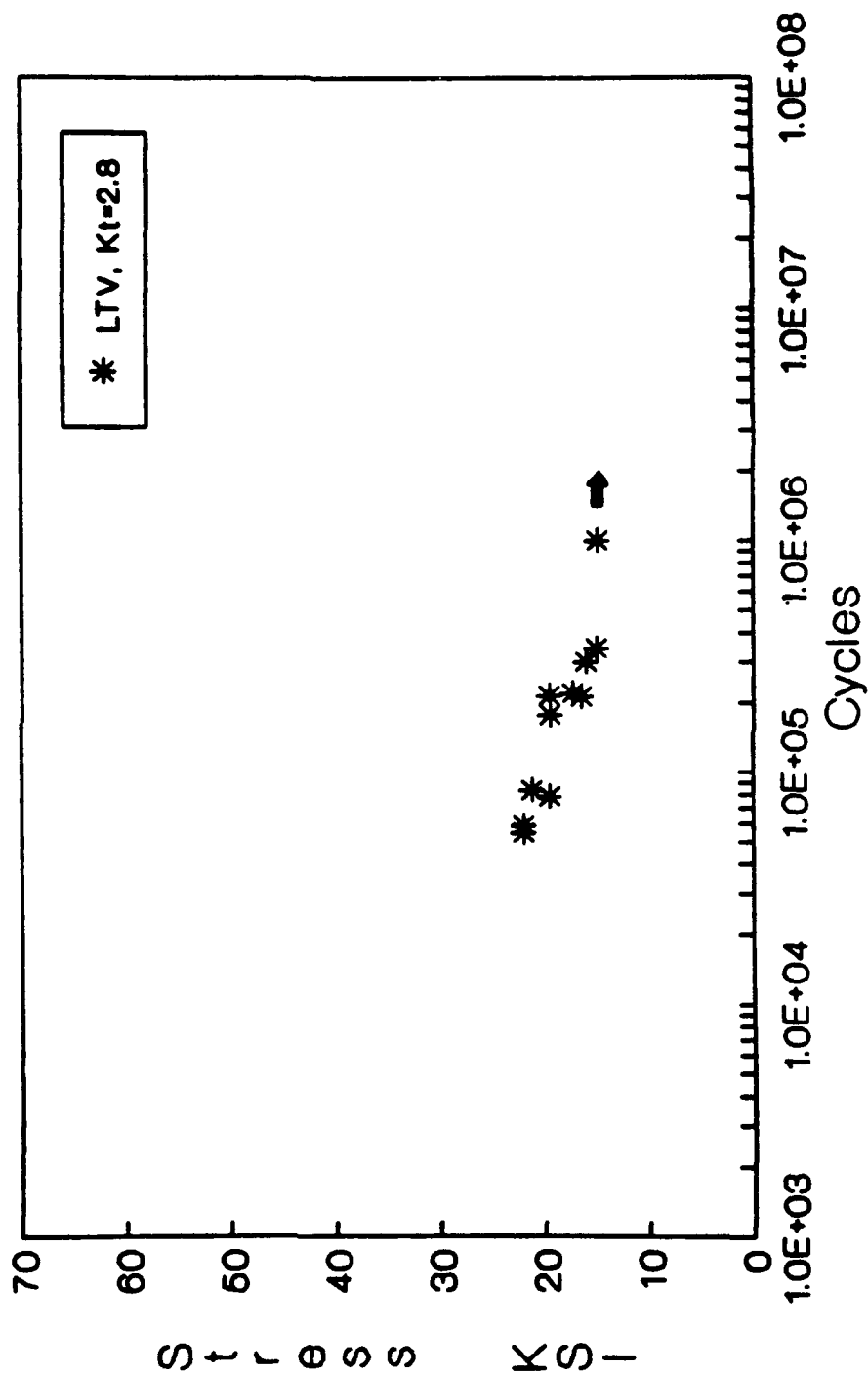


Figure D1 Fatigue Results for 8090-T651 T-Extrusion (R=0.1, Kt=2.8). LTV.

## APPENDIX E

### ALCAN 8090-T651 AND 8090-T8 EXTRUSION (1.0" X 4.0")

#### INTRODUCTION

The Alcan 8090-T651 1-inch x 4-inch extrusions were received the first quarter of 1986. One participant heat treated the 8090-T651 to a T8 temper. Grumman-T8 condition was achieved by heating the material to 338°F for 24 hours. The other participants tested the material in the as-received condition (-T651).

#### TESTING

Basic mechanical properties (tension, compression, bearing, etc.) were tested according to ASTM standards, unless otherwise specified.

Constant amplitude fatigue crack growth tests were conducted according to ASTM E647 standard. The growth rate  $a-N$  data that were generated by the participants (Northrop, Grumman, and Air Force) were reduced using a seven-point incremental polynomial method. This involves fitting a second-order polynomial (parabola) to sets of seven successive data points. The data are also checked against size requirements per ASTM E647, Section 7.2. NASA-Langley performed constant amplitude fatigue crack growth tests using K-increasing (load increasing) and K-decreasing (load decreasing) methods.

Spectrum tests were performed by the Air Force using FALSTAFF ( a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

TABLE E1

## TENSILE RESULTS AT t/2 LOCATION FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	LONG	72.7	62.9	5.3	13.0	
			76.1	64.2	5.3	6.0	
			77.0	65.2	6.1	9.9	
			76.6	65.2	5.3	9.9	
			74.2	62.2	5.7	8.5	
			76.8	64.9	5.6	7.0	
MARTIN MARIETTA	RT	LONG	81.0	76.8	4.9		11.3
			73.1	63.5	6.2		11.3
			81.1	77.2	7.9		11.2
NORTHROP	RT	LONG	73.7	65.6	4.0	19.6	11.8
			76.4	68.5	6.0	20.8	11.6
			79.9	76.5	4.0	19.4	11.7
			76.6	71.1	7.0		12.0
			73.1	64.8	7.0		12.5
			73.9	65.5	7.0		12.5
NASA LANGLEY	RT	LONG	77.1	67.9	5.0		11.4
			75.8	66.6	10.0		11.3
			76.4	67.5	9.0		11.4
			77.0	68.0	7.5		11.4
AVERAGE			76.2	67.6	6.3	12.7	11.6
STANDARD DEVIATION			2.5	4.6	1.6	5.8	0.4

TABLE E2

## TENSILE RESULTS AT t/2 LOCATION FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	-423	LONG	103.9		22.0		13.1
MARIETTA			102.9	52.7	8.0		12.9
			99.8	62.0	16.0		12.3
			123.6		14.0		14.4
			107.0	71.3	20.0		13.4
	-320	LONG	89.4	64.4	12.0		14.9
			89.4	68.6	11.0		13.5
			89.1	64.5			13.5
	+200	LONG	68.3	65.6	16.0		11.0
			69.6	63.9	14.0		11.2
			69.3	66.0	18.0		12.4
	+350	LONG	55.3	55.2	36.0		10.5
			55.6	55.5	26.0		10.5
			55.7	55.6	30.0		10.7

TABLE E3

## TENSILE RESULTS AT t/2 LOCATION FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	L TRANS	67.4	54.7	7.8	16.0	
			68.2	54.0	0.0	15.9	
			69.6	55.0	8.6	21.8	
NORTHROP	RT	L TRANS	68.6	58.4	7.0	19.6	11.8
			68.3	58.1	7.0	20.8	11.6
			68.2	58.0	7.0	19.4	11.7
			68.0	58.0	8.0		12.3
			67.8	57.2	8.0		12.5
			68.2	58.2	9.0		12.2
MARTIN MARIETTA	RT	L TRANS	67.9	56.1	8.0		11.1
			68.2	56.8	9.5		11.1
			68.5	56.5	9.5		11.5
NASA LANGLEY	RT	L TRANS	70.5	57.8	10.0		11.4
			70.1	57.7	11.0		11.4
			70.8	58.3	10.0		11.4
			70.7	57.8	10.0		11.4
AVERAGE			68.8	57.0	8.2	18.9	11.6
STANDARD DEVIATION			1.1	1.4	2.5	2.5	0.4

TABLE B4

TENSILE RESULTS AT  $t/2$  LOCATION FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	-423	L TRANS	86.9	62.6	8.0		12.5
MARIETTA			81.8	72.0			12.5
			87.9	62.5	9.0		13.1
	-320	L TRANS	78.9	60.6	5.0		13.6
			79.3	60.2	8.0		13.5
			77.3	60.1			13.2
	+200	L TRANS	63.5	56.1	12.3		9.0
			63.6	56.5	13.3		10.6
			63.6	56.7	12.5		10.8
	+350	L TRANS	50.7	50.6	22.0		10.4
			51.4	51.2	18.0		10.0
			58.5	56.3	18.0		10.0

TABLE E5

## TENSILE RESULTS AT t/2 LOCATION FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	S TRANS	69.4	55.9	8.0	7.8	11.1
			68.0	52.4	4.0	3.1	11.3
			66.5	51.6	4.0	3.1	11.2
		AVERAGE	68.0	53.3	5.3	4.7	11.2
		STANDARD DEVIATION	1.5	2.3	2.3	2.7	0.1

TABLE E6

## TENSILE RESULTS AT t/10 LOCATION FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	LONG	77.9	69.0	6.0		12.0
			75.7	66.8	5.0		12.2
			74.1	65.1	5.0		11.9
		AVERAGE	75.9	67.0	5.3		12.0
		STANDARD DEVIATION	1.9	2.0	0.6		0.2

TABLE E7

## TENSILE RESULTS AT t/10 LOCATION FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	L TRANS	72.4	63.4	9.0		12.4
			72.2	63.1	9.0		12.2
			72.3	63.0	9.0		12.2
		AVERAGE	72.3	63.2	9.0		12.3
		STANDARD DEVIATION	0.1	0.2	0.0		0.1

TABLE E8

## TENSILE RESULTS AT t/2 LOCATION FOR ALCAN

8090-T651 EXTRUSION (1" x 4") AFTER 100 HRS AT 350F

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	LONG	78.0	72.1	7.0	14.5	11.6
			73.6	66.8	7.0	12.3	12.5
			72.3	65.0	7.0	10.9	11.8
		AVERAGE	74.6	68.0	7.0	12.6	12.0
	STANDARD DEVIATION	3.0	3.7	0.0	1.8	0.5	
	RT	L TRANS	68.1	60.4	6.0	13.8	11.5
			68.2	60.4	6.0	13.8	12.3
			68.1	60.5	6.0	13.8	12.9
		AVERAGE	68.1	60.4	6.0	13.8	12.2
	STANDARD DEVIATION	0.1	0.1	0.0	0.0	0.7	
	RT	S TRANS	67.2	56.9	4.0	6.2	11.3
			64.8	55.8	2.0	2.5	10.8
			67.1	55.2	2.0	4.7	10.8
		AVERAGE	66.4	56.0	2.7	4.5	11.0
	STANDARD DEVIATION	1.4	0.9	1.2	1.9	0.3	

**TABLE E9**  
**NOTCH TENSILE RESULTS AT t/2 LOCATION FOR ALCAN**  
**8090-T651 EXTRUSION (1" x 4")**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	NTS (KSI)	NTS/TYS
NORTHROP	RT	LONG	82.7	1.2
			78.1	1.1
			85.0	1.2
	AVERAGE		81.9	1.2
	STANDARD DEVIATION		3.5	0.1
	RT	L TRANS	60.5	1.0
			54.1	0.9
			50.3	0.9
	AVERAGE		55.0	0.9
	STANDARD DEVIATION		5.2	0.0

TABLE E10

## COMPRESSION RESULTS FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
AIR FORCE	RT	LONG	69.1 69.4 69.0	
NORTHROP	RT	LONG	74.6 71.9 71.8	12.0 12.0 11.9
NASA LANGLEY	RT	LONG	67.4 66.9 66.9	11.7 11.7 11.7
		AVERAGE	69.7	11.8
		STANDARD DEVIATION	2.6	0.2

TABLE E11

## COMPRESSION RESULTS FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
AIR FORCE	RT	L TRANS	65.5 64.5 65.2	
NORTHROP	RT	L TRANS	64.9 65.3 62.5	12.1 11.9 12.3
NASA LANGLEY	RT	L TRANS	63.2 63.1 63.9 63.4	11.8 11.5 11.8 11.8
		AVERAGE	64.2	11.9
		STANDARD DEVIATION	1.1	0.3

TABLE E12  
RIVET SHEAR RESULTS FOR ALCAN  
8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
<hr/>		
NORTHROP	L - S	36.9
		37.4
		37.1
	AVERAGE	37.1
	STANDARD DEVIATION	0.3

TABLE E13  
RIVET SHEAR RESULTS FOR ALCAN  
8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
<hr/>		
NORTHROP	T - S	34.5
		34.6
		36.6
	AVERAGE	35.2
	STANDARD DEVIATION	1.2

**TABLE E14**  
**AMSLER DOUBLE SHEAR RESULTS FOR**  
**ALCAN 8090-T651 EXTRUSION (1" X 4")**

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
-----		
AIR FORCE	L - S	36.5
		34.6
		34.7
NASA - LANGLEY	L - S	36.7
		36.7
		36.4
		37.0
AVERAGE		36.1
STANDARD DEVIATION		1.0

**TABLE E15**  
**AMSLER DOUBLE SHEAR RESULTS FOR**  
**ALCAN 8090-T651 EXTRUSION (1" X 4")**

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
-----		
AIR FORCE	T - S	36.5
		36.6
		34.6
NASA - LANGLEY	T - S	35.4
		35.1
		35.0
		34.8
AVERAGE		35.4
STANDARD DEVIATION		0.8

TABLE E16  
BEARING RESULTS FOR ALCAN  
8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	e/D	BEARING		BEARING
			ULT.	STR.	YIELD STR.
			(KSI)		(KSI)
AIR FORCE	LONG	1.5		94.2	74.3
				100.6	82.7
				100.4	79.3
NORTHROP	LONG	1.5		101.0	84.4
				99.4	77.7
				100.0	81.5
NASA LANGLEY	LONG	1.5		104.5	86.1
				103.2	85.5
				101.9	82.4
				103.5	84.3
AVERAGE				100.9	81.8
STANDARD DEVIATION				2.9	3.7

TABLE E17  
BEARING RESULTS FOR ALCAN  
8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	e/D	BEARING		BEARING
			ULT.	STR.	YIELD STR.
			(KSI)		(KSI)
AIR FORCE	L TRANS	1.5		88.3	79.4
				80.0	71.8
				87.4	78.2
NORTHROP	L TRANS	1.5		87.7	79.5
				88.3	80.1
				86.3	78.9
AVERAGE				86.3	78.0
STANDARD DEVIATION				3.2	3.1

TABLE E18  
BEARING RESULTS FOR ALCAN  
8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
AIR FORCE	LONG	2.0	123.0 126.0 116.7	87.0
NORTHROP	LONG	2.0	126.0 125.0 128.0	98.3 94.8 97.1
NASA LANGLEY	LONG	2.0	131.4 131.0 127.0 132.4	100.0 97.4 98.1 97.4
AVERAGE			126.7	96.3
STANDARD DEVIATION			4.6	4.0

TABLE E19  
BEARING RESULTS FOR ALCAN  
8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
AIR FORCE	L TRANS	2.0	116.0 115.1 104.7	98.0 90.3 86.6
NORTHROP	L TRANS	2.0	116.0 115.0	98.3 98.3
AVERAGE			113.4	94.3
STANDARD DEVIATION			4.9	5.5

**TABLE E20**  
**FRACTURE TOUGHNESS RESULTS FOR**  
**ALCAN 8090-T651 EXTRUSION (1" X 4")**

COMPANY	ORIENTATION	K <sub>IC</sub> (KSI in <sup>0.5</sup> )	K <sub>q</sub> (KSI in <sup>0.5</sup> )	COMMENT
AIR FORCE	L - T	25.8	25.2	INVALID(1)
				VALID
			27.8	INVALID(1,2)
NORTHROP	L - T	26.2		(3)
		28.3		(3)
		28.4		(3)
NASA LANGLEY	L - T		25.3	INVALID(1,2)
			28.1	INVALID(1,2)
			27.4	INVALID(1,2)
			28.9	INVALID(1,2)
	AVERAGE	27.2	27.1	
	STANDARD DEVIATION	1.4	1.5	

(1): P<sub>max</sub>/P<sub>q</sub> was greater than 1.10

(2): The difference between the two surface crack length measurements exceed 10% of the average crack length.

(3): Fractured parallel to load line

**TABLE E21**  
**FRACTURE TOUGHNESS RESULTS FOR**  
**ALCAN 8090-T651 EXTRUSION (1" X 4")**

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
-----				
AIR FORCE	T - L	16.1		VALID
		16.3		VALID
		15.9		VALID
NORTHROP	T - L	15.1		VALID
		14.9		VALID
		15.3		VALID
NASA LANGLEY	T - L		5.4	INVALID(1,2)
			6.8	INVALID(1,3)
			17.1	INVALID(1)
			17.9	INVALID(1)
AVERAGE		15.6	11.8	
STANDARD DEVIATION		0.6		

- (1):  $K_{max} > 0.6 Kq$   
(2):  $P_{max} / Pq = 3.6$   
(3):  $P_{max} / Pq = 2.6$

**TABLE E22**  
**STRESS CORROSION CRACKING RESULTS FOR**  
**ALCAN 8090-T651 EXTRUSION (1" X 4")**

COMPANY	ORIENTATION	STRESS APPLIED (KSI in <sup>0.5</sup> )	% OF T-L KIC (KSI in <sup>0.5</sup> )	COMMENT
AIR FORCE	T-L	12.0	75.0	DID NOT FAIL
		14.0	87.0	DID NOT FAIL

**NOTE: TESTING DISCONTINUED AFTER SPECIMEN WAS LOADED TO 87% OF T-L KIC AND DID NOT FAIL AFTER 2000 HRS.**

**TABLE E23**  
**FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR**  
**ALCAN 8090-T651 EXTRUSION (1" X 4")**

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
NORTHROP	LONG	80.0	98
		70.0	18,793
		60.0	28,082
		50.0	57,511
		45.0	362,662
		42.5	642,818
		40.0	4,000,000 *
		37.5	5,000,000 *
NASA - LANGLEY	LONG	60.0	29,100
		50.0	43,000
		45.0	55,600
		40.0	549,000
		38.0	2,472,100
		36.0	10,557,700 *
		36.0	139,300
		36.0	317,600
		30.0	12,900,000 *

(\*): INDICATES RUN-OUT TEST

# Alcan 8090-T651 Extrusion (1" X 4")

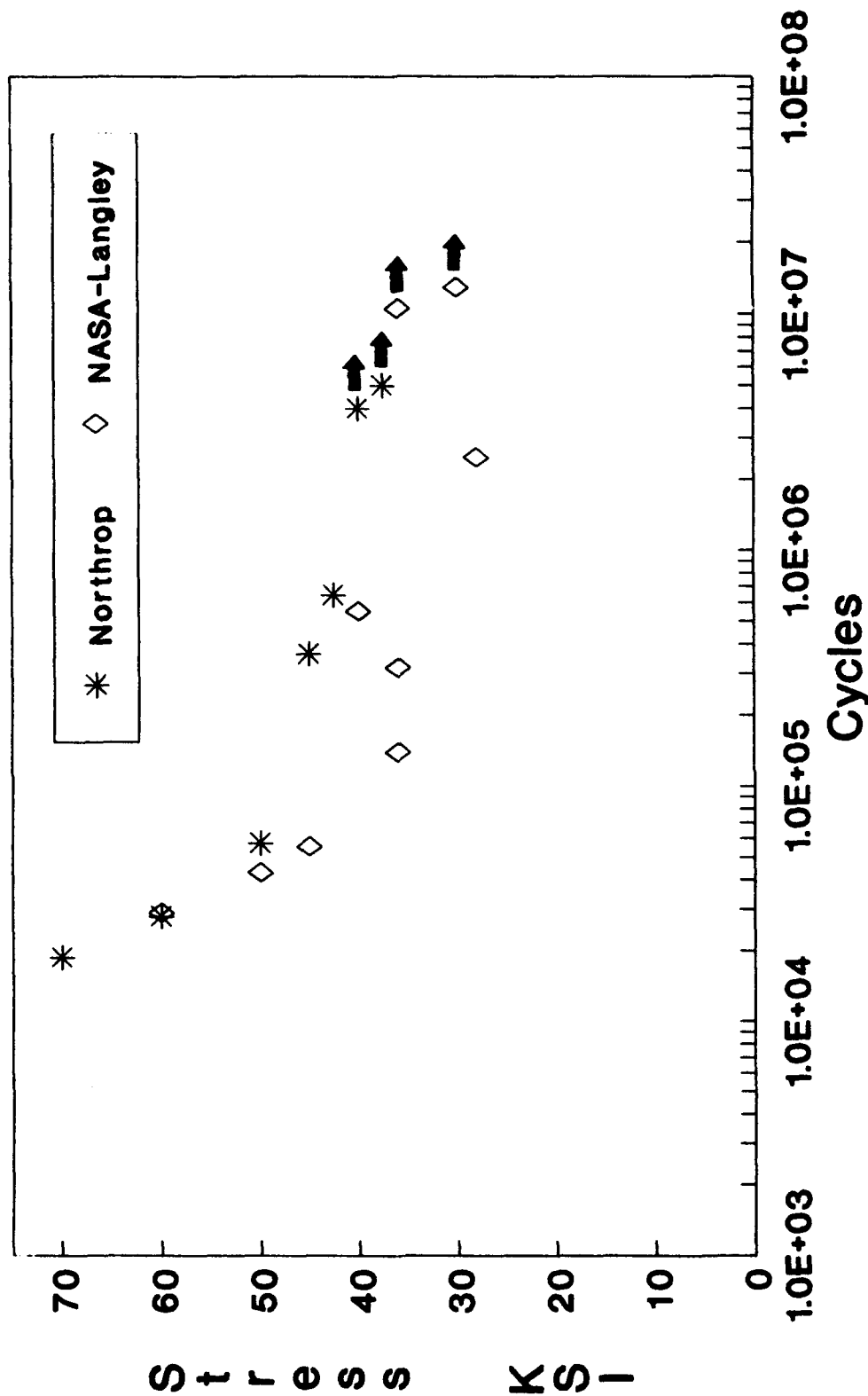


Figure E1. Fatigue Results for 8090-T651 1" x 4" Extrusion ( $R=0.1$ ,  $K_t=1.0$ , Longitudinal).

**TABLE E24**

**FATIGUE RESULTS WITH R=0.1 AND Kt=3.0 FOR**

**ALCAN 8090-T651 EXTRUSION (1" X 4")**

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
-----			
NORTHROP	LONG	55.0	4,413
		50.0	6,373
		40.0	13,431
		35.0	35,620
		30.0	115,117
		27.5	210,968
		27.5	150,596
		25.0	5,000,000 *
NASA - LANGLEY	LONG	35.0	20,400
		30.0	47,600
		25.0	462,400
		23.0	1,785,300
		22.0	1,169,200
		22.0	725,500
		22.0	12,300,000 *
		21.0	10,908,100 *
	20.0	10,045,000 *	

**(\*) : INDICATES RUN-OUT TEST**

**NOTE: NASA-LANGLEY SPECIMENS HAD A Ktg=3.01 AND A Ktn=2.88**

# Alcan 8090-T651 Extrusion (1" X 4")

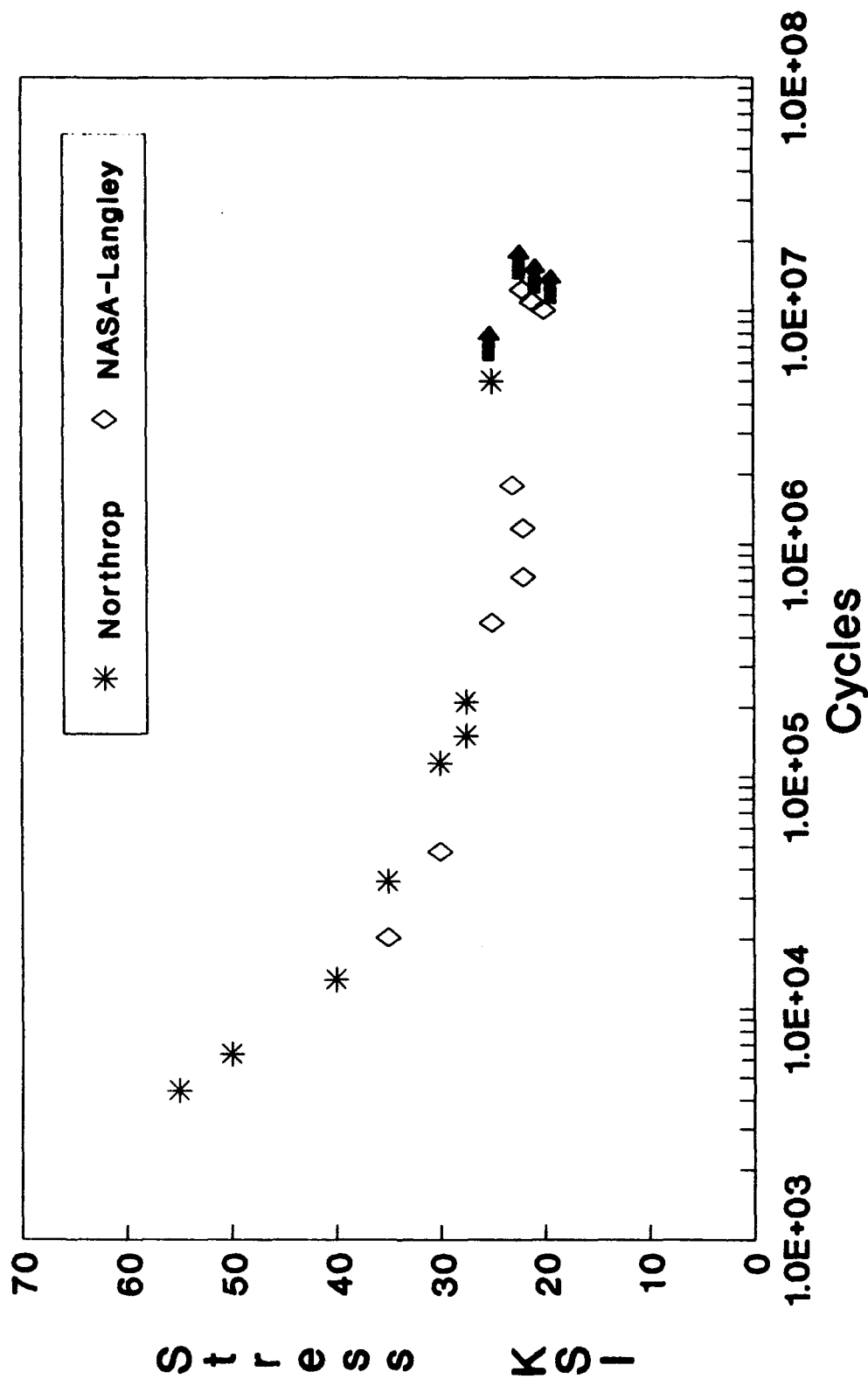


Figure E2. Fatigue Results for 8090-T651 1" x 4" Extrusion ( $R=0.1$ ,  $K_t=3.0$ , Longitudinal).

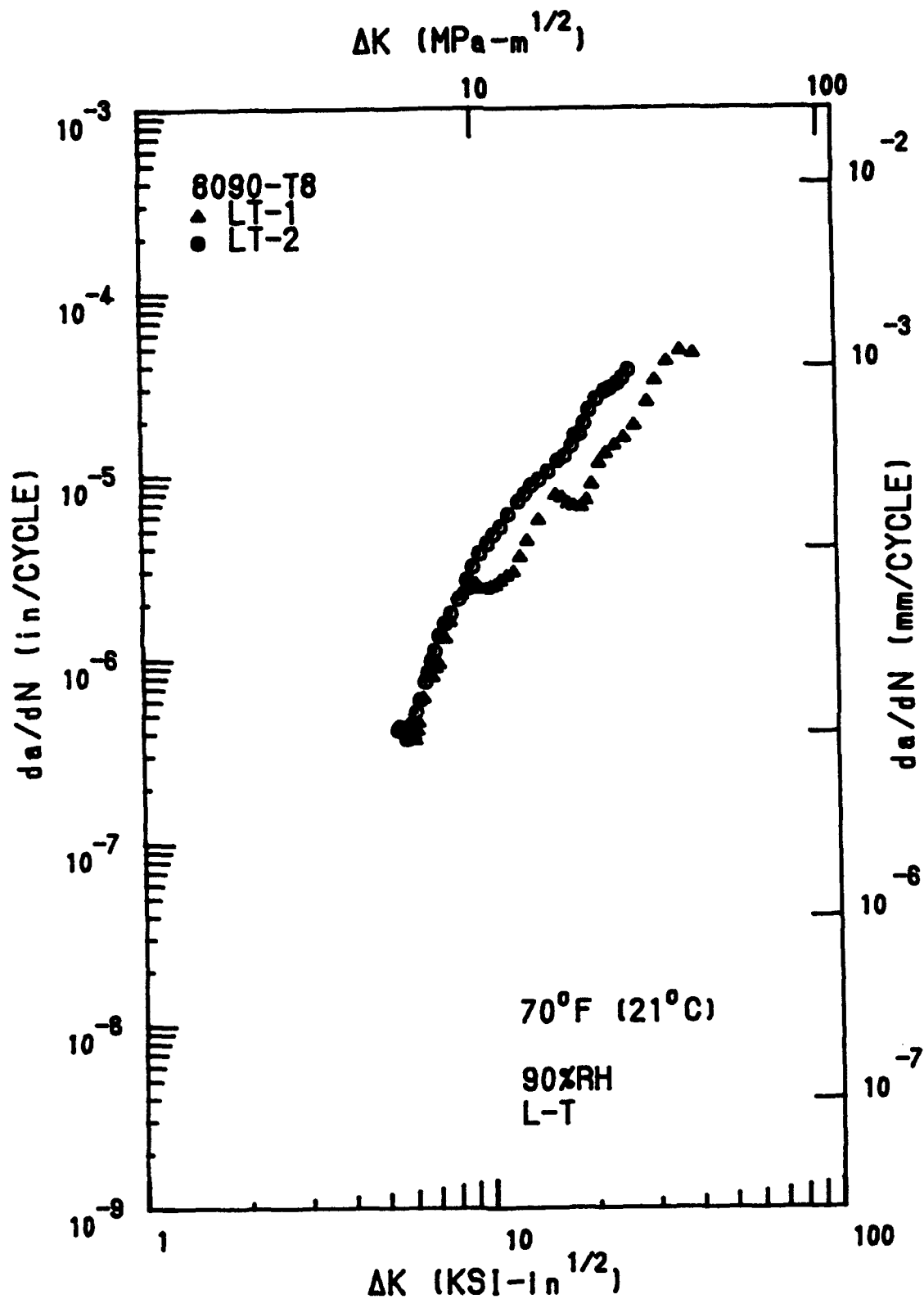


Figure E3. Fatigue Crack Growth Rate Data for Alcan 8090-T8 1" x 4" Extrusion (L-T Orientation). Grumman.

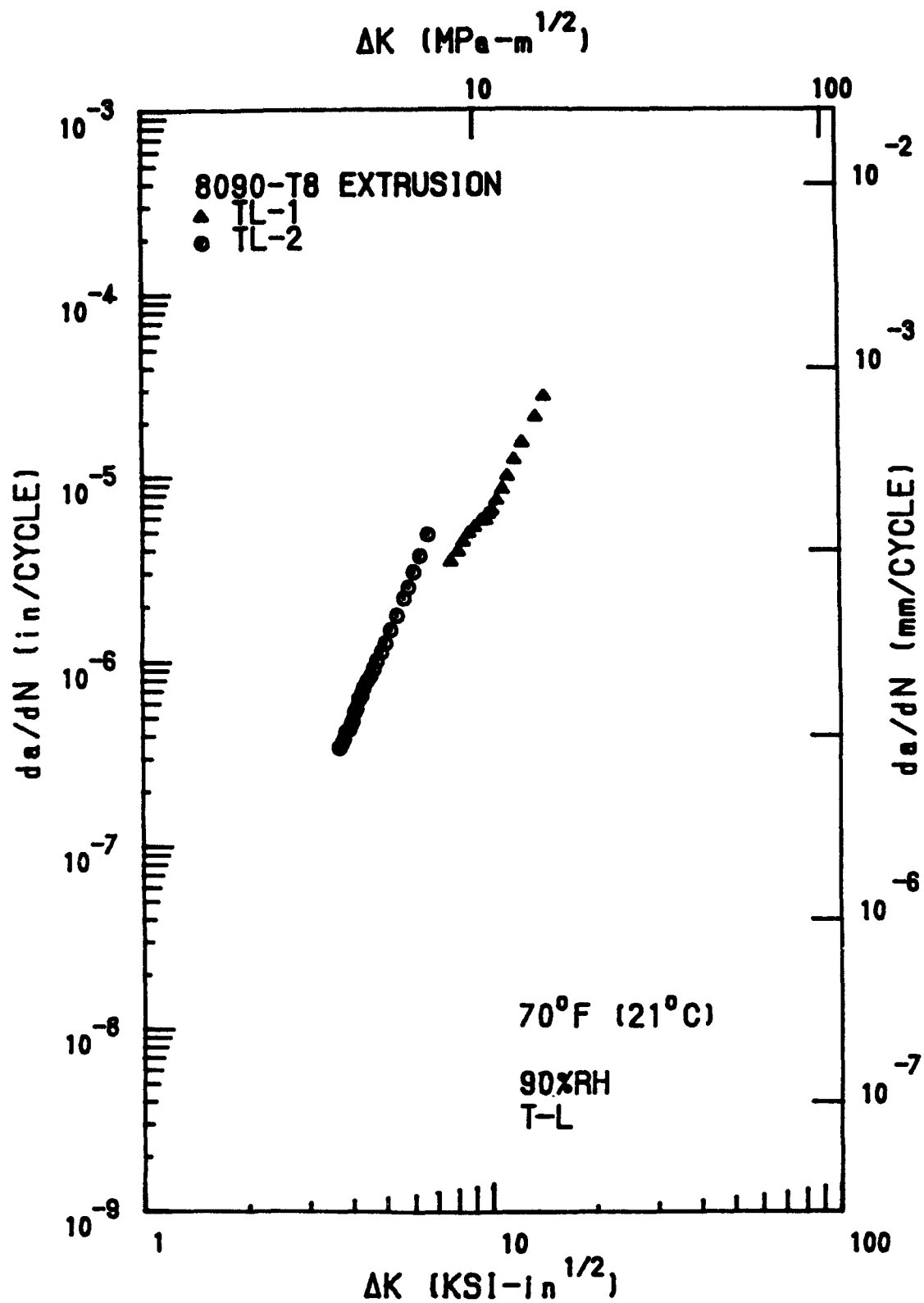


Figure E4 . Fatigue Crack Growth Rate Data for Alcan 8090-T8 1" x 4" Extrusion (T-L Orientation). Grumman.

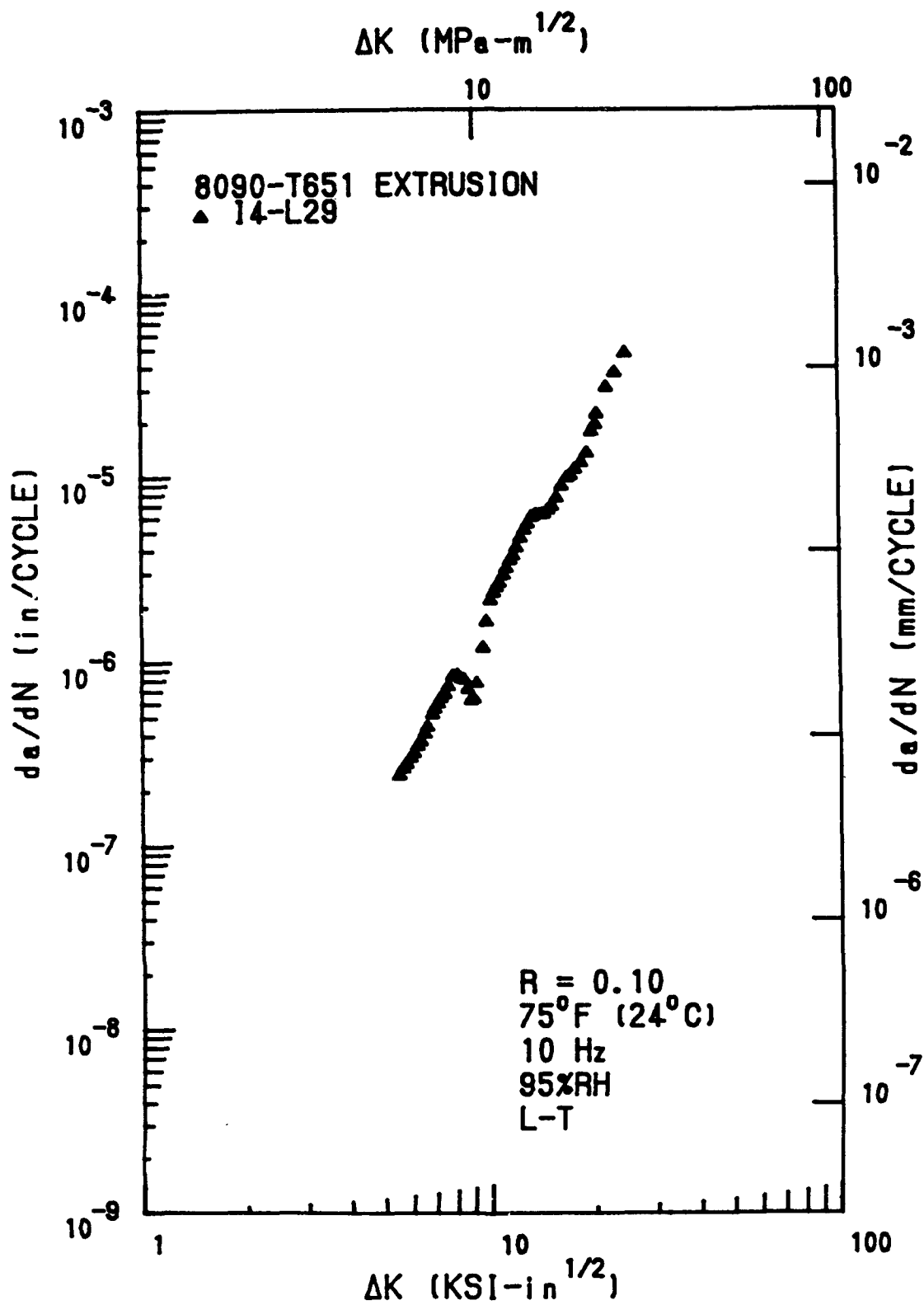


Figure E5. Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (L-T Orientation). Northrop.

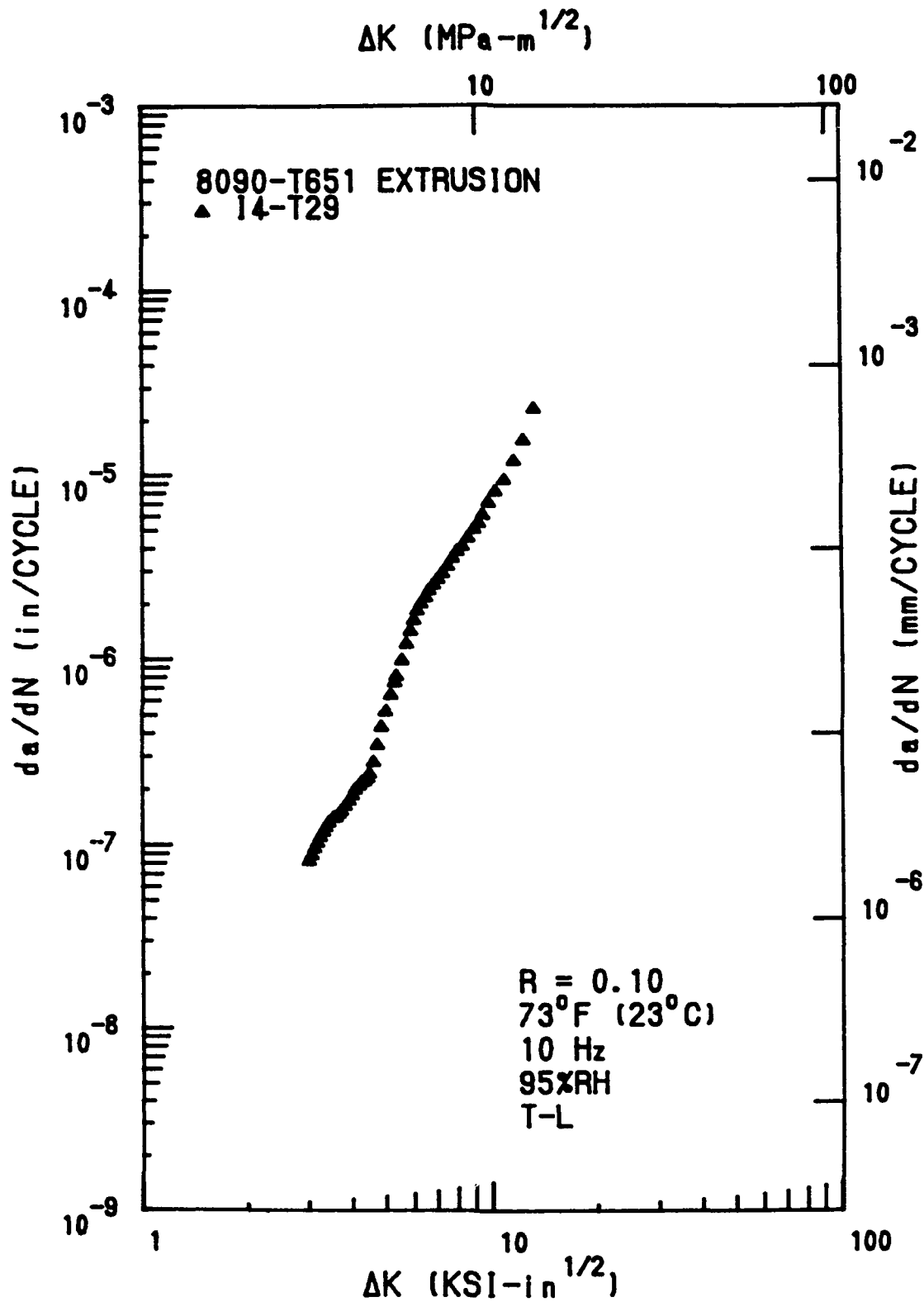


Figure E6. Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (T-L orientation). Northrop.

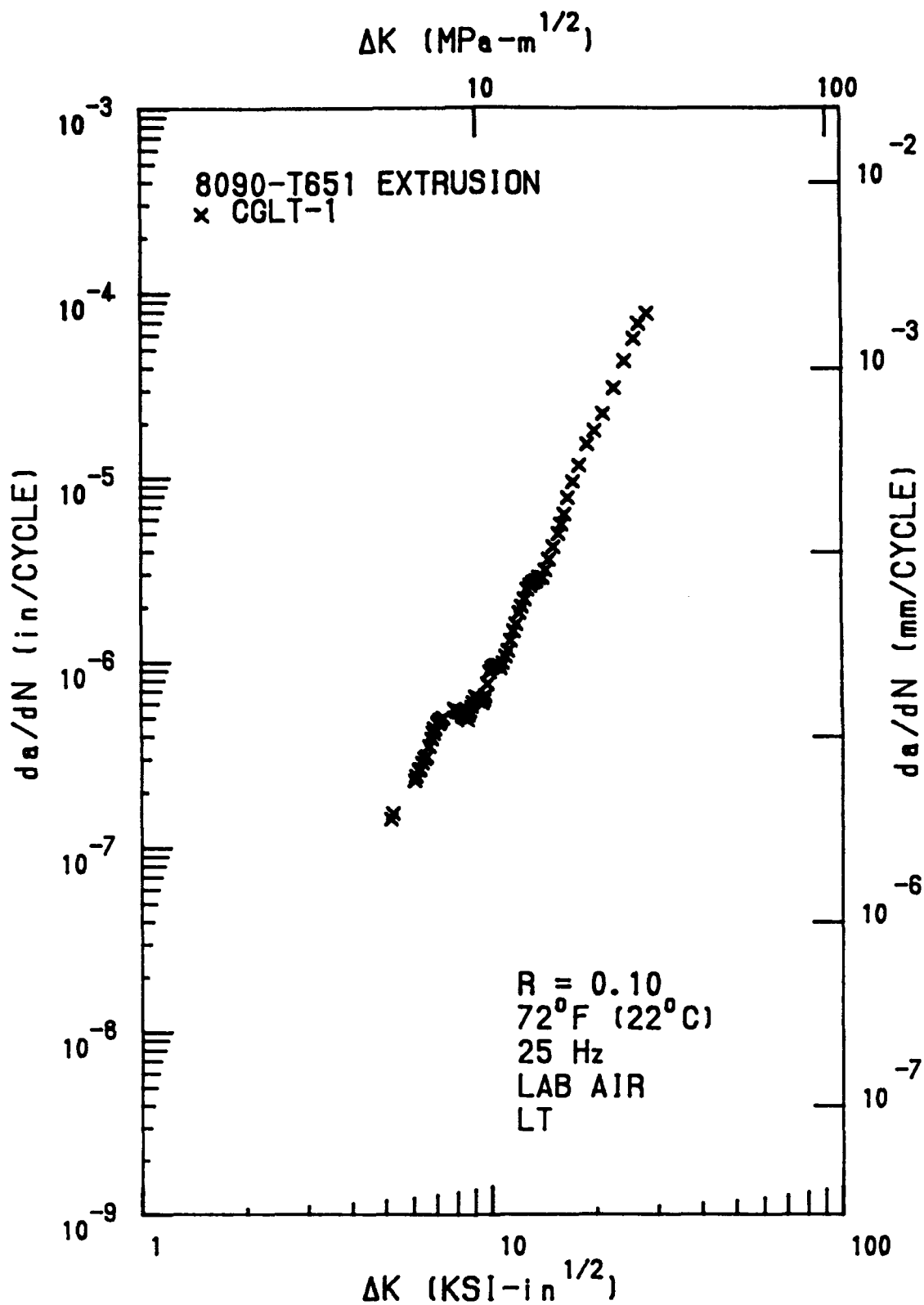


Figure E7. Fatigue Crack Growth Rate Data for Alcan 8090-T651  
1" x 4" Extrusion (L-T Orientation). U.S. Air Force.

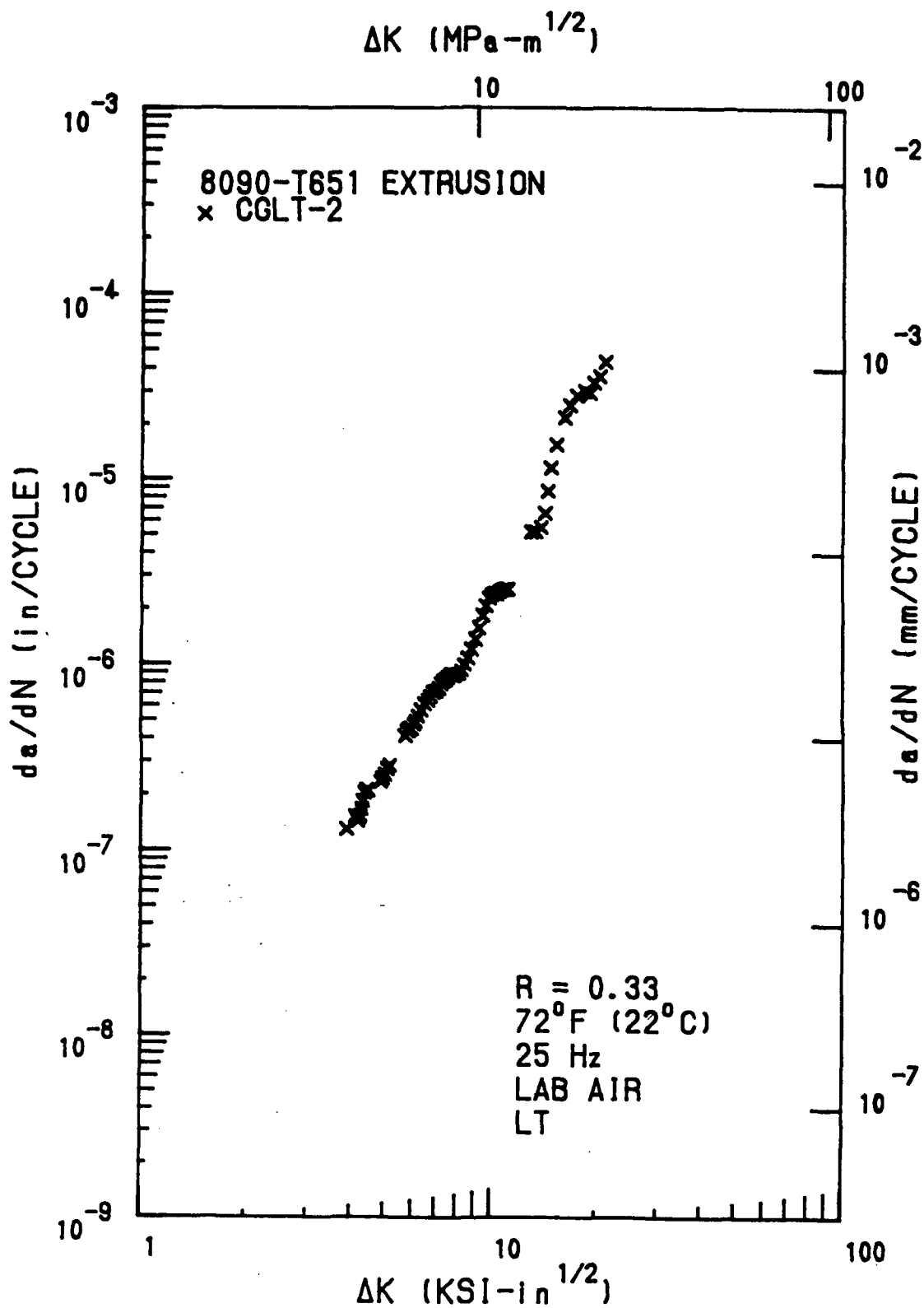


Figure E8. Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (L-T Extrusion). U.S. Air Force.

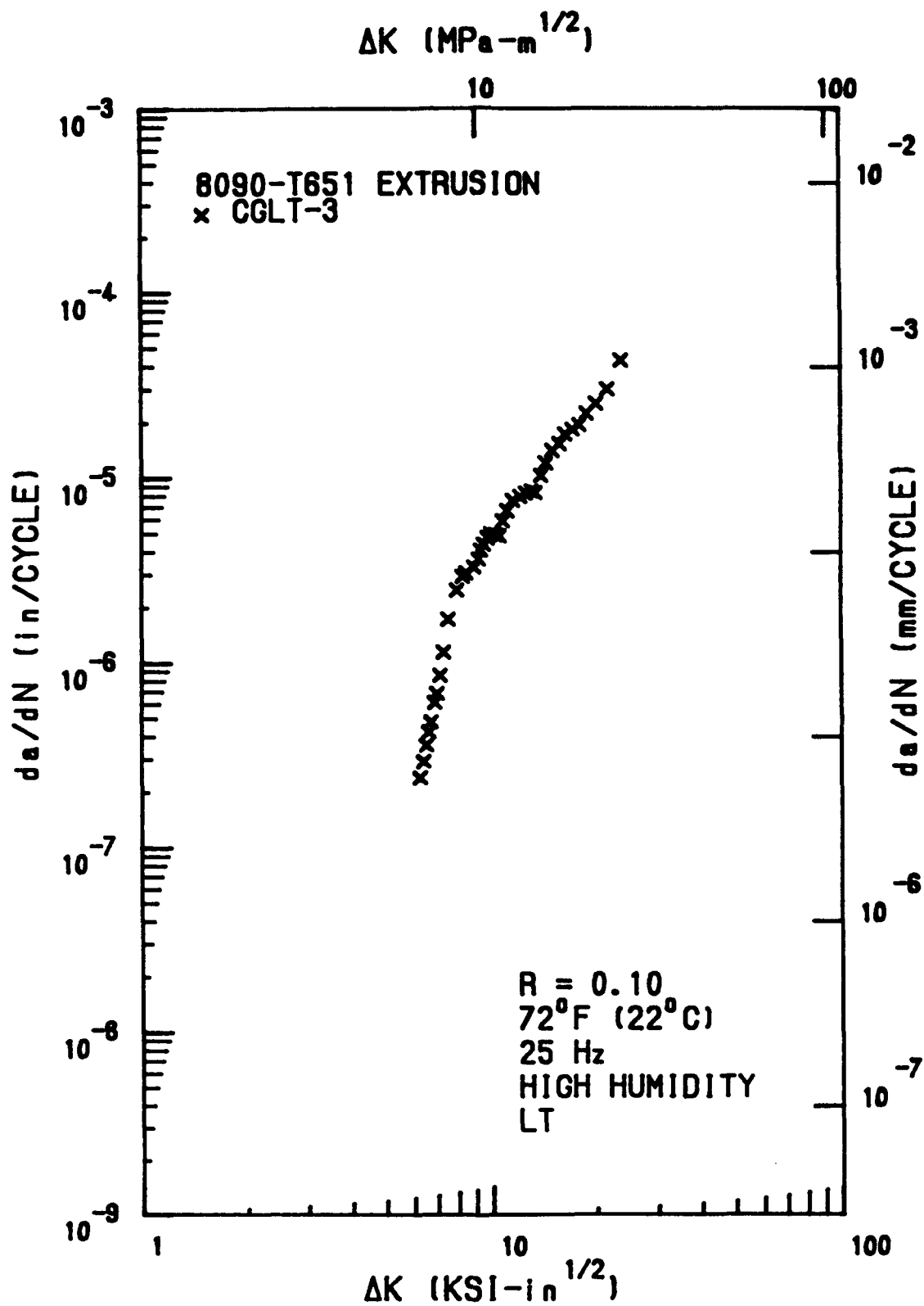


Figure E9. Fatigue Crack Growth Rate Data for Alcan 8090-T651  
1" x 4" Extrusion (L-T Orientation). U.S. Air Force.

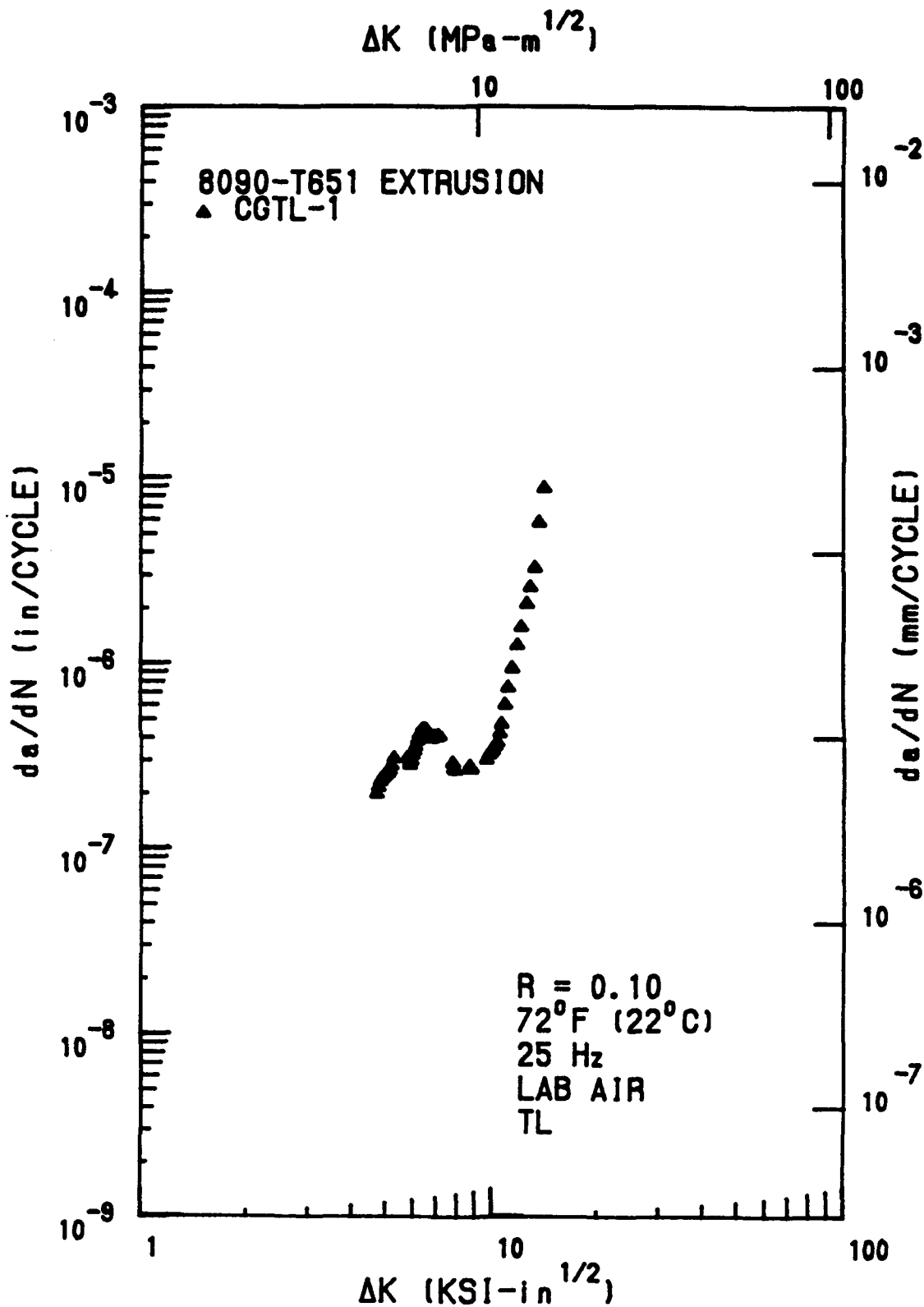


Figure E10. Fatigue Crack Growth Rate Data for Alcan 8090-T651  
1" x 4" Extrusion (T-L Orientation). U.S. Air Force.

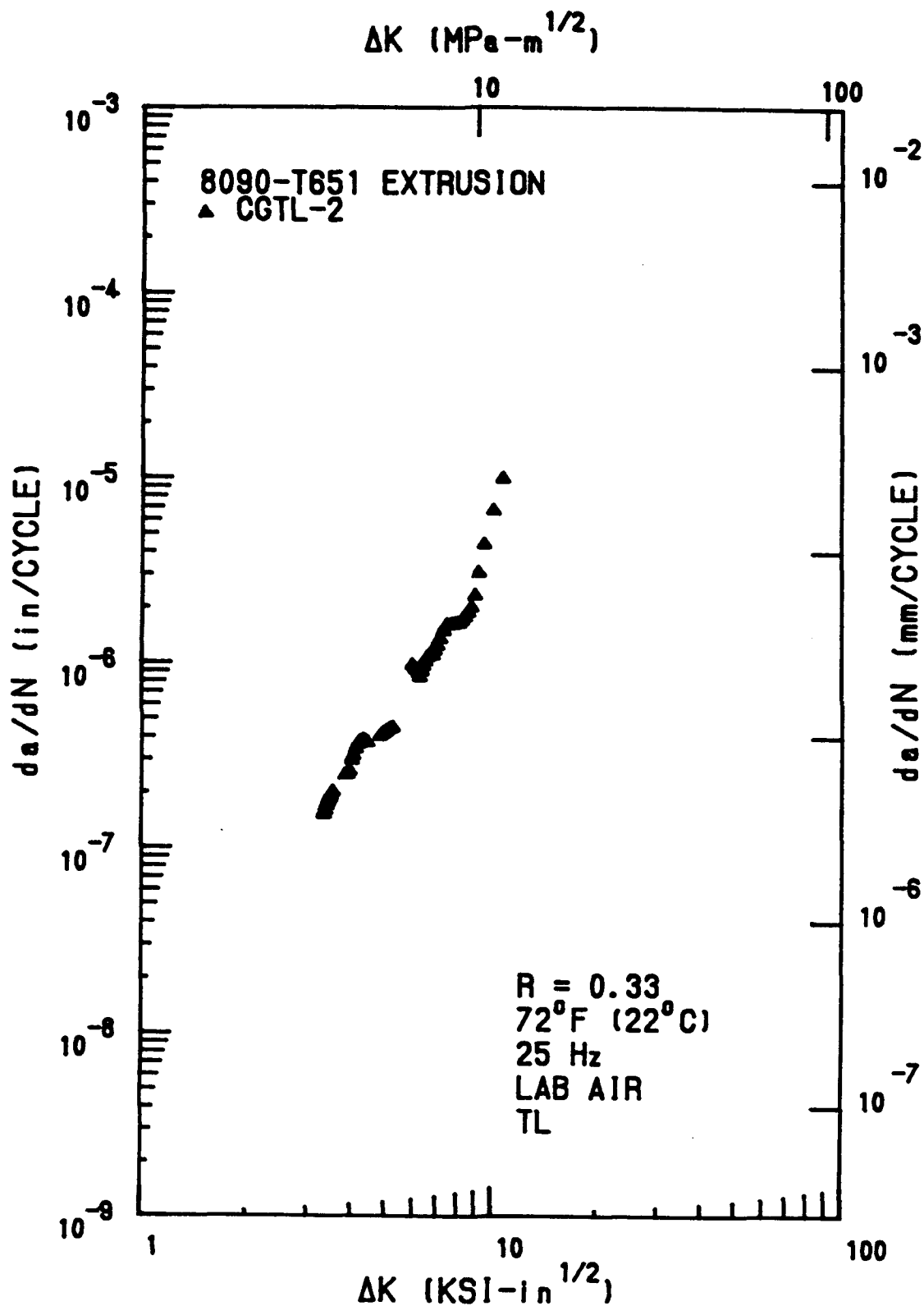


Figure E11. Fatigue Crack Growth Rate Data for Alcan 8090-T651  
1" x 4" Extrusion (T-L Orientation). U.S. Air Force.

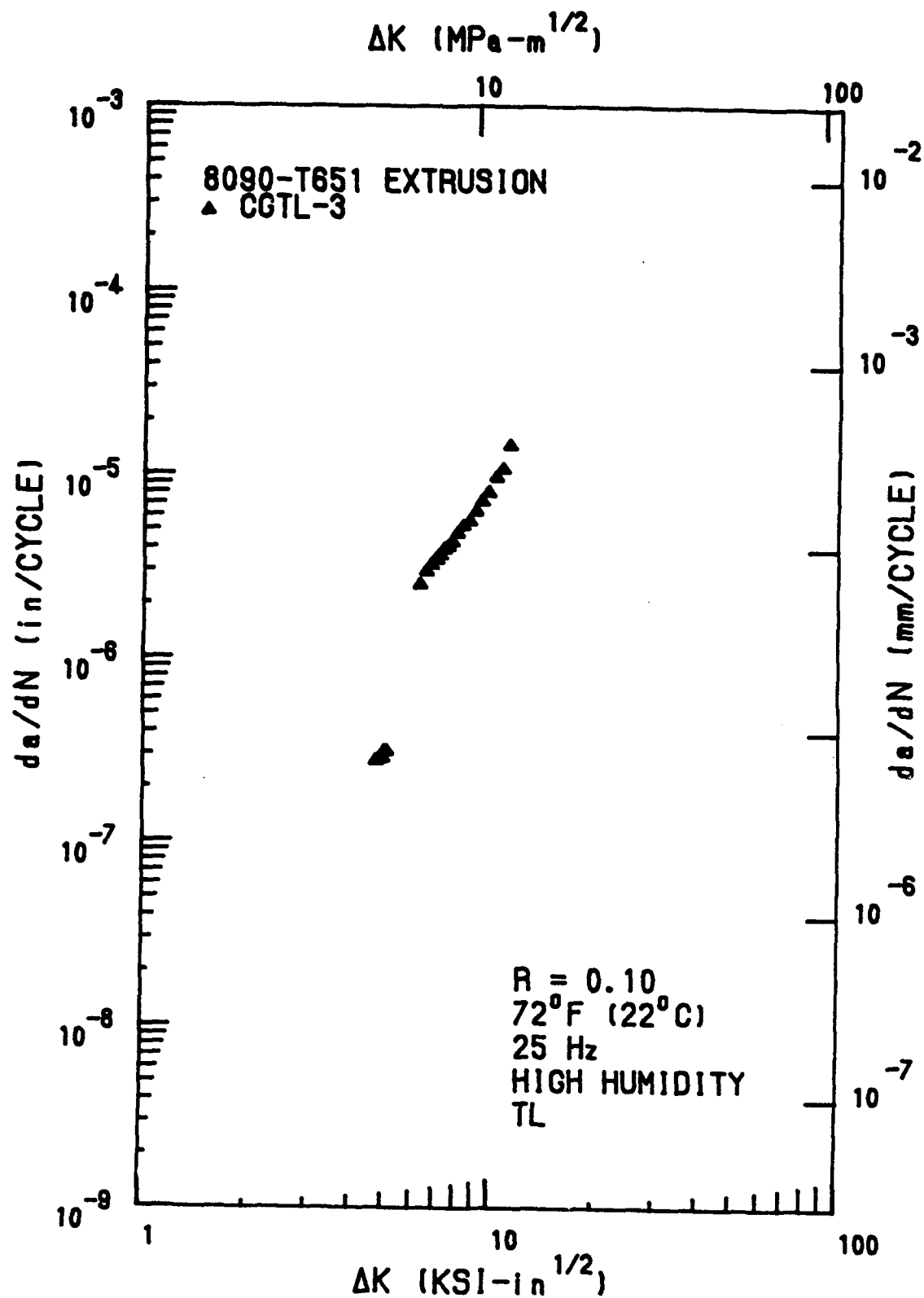


Figure E12. Fatigue Crack Growth Rate Data for Alcan 8090-T651  
1" x 4" Extrusion (T-L Orientation). U.S. Air Force.

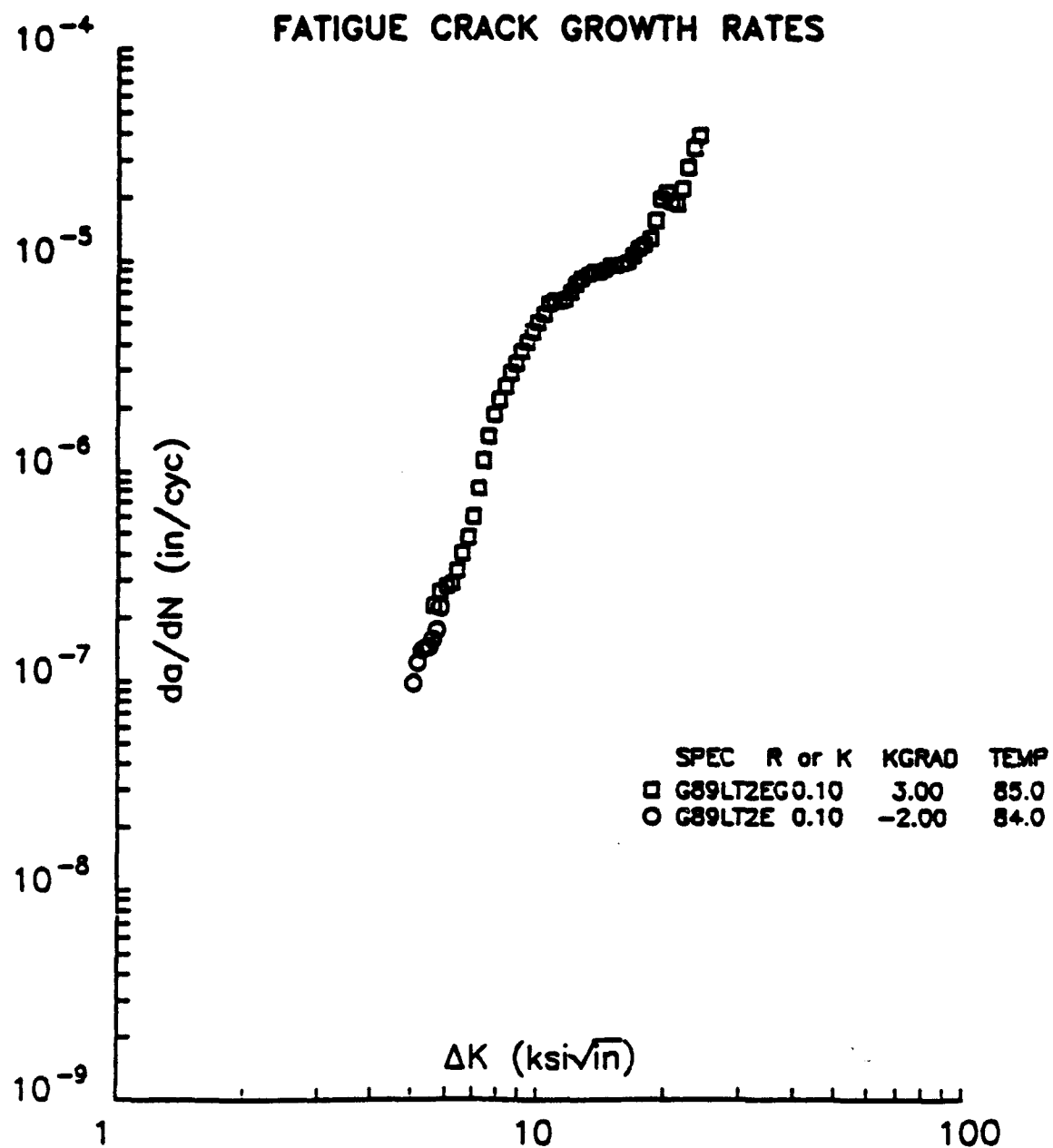


Figure E13. Fatigue Crack Growth Rate Data for Alcan 8090-T651  
1" x 4" Extrusion (L-T Orientation). NASA-Langley.

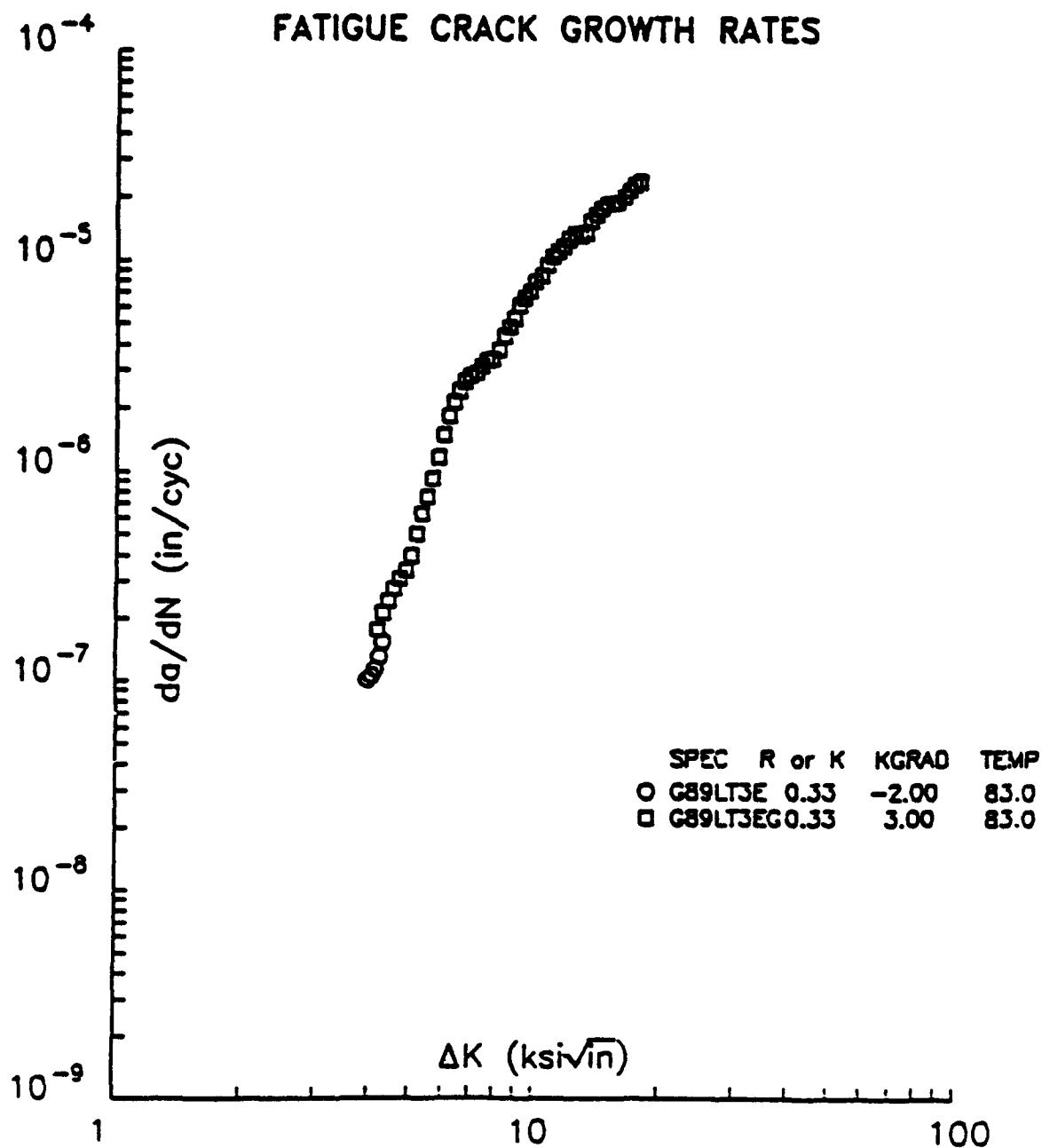


Figure E14. Fatigue Crack Growth Rate Data for Alcan 8090-T651  
1" x 4" Extrusion (L-T Orientation). NASA-Langley.

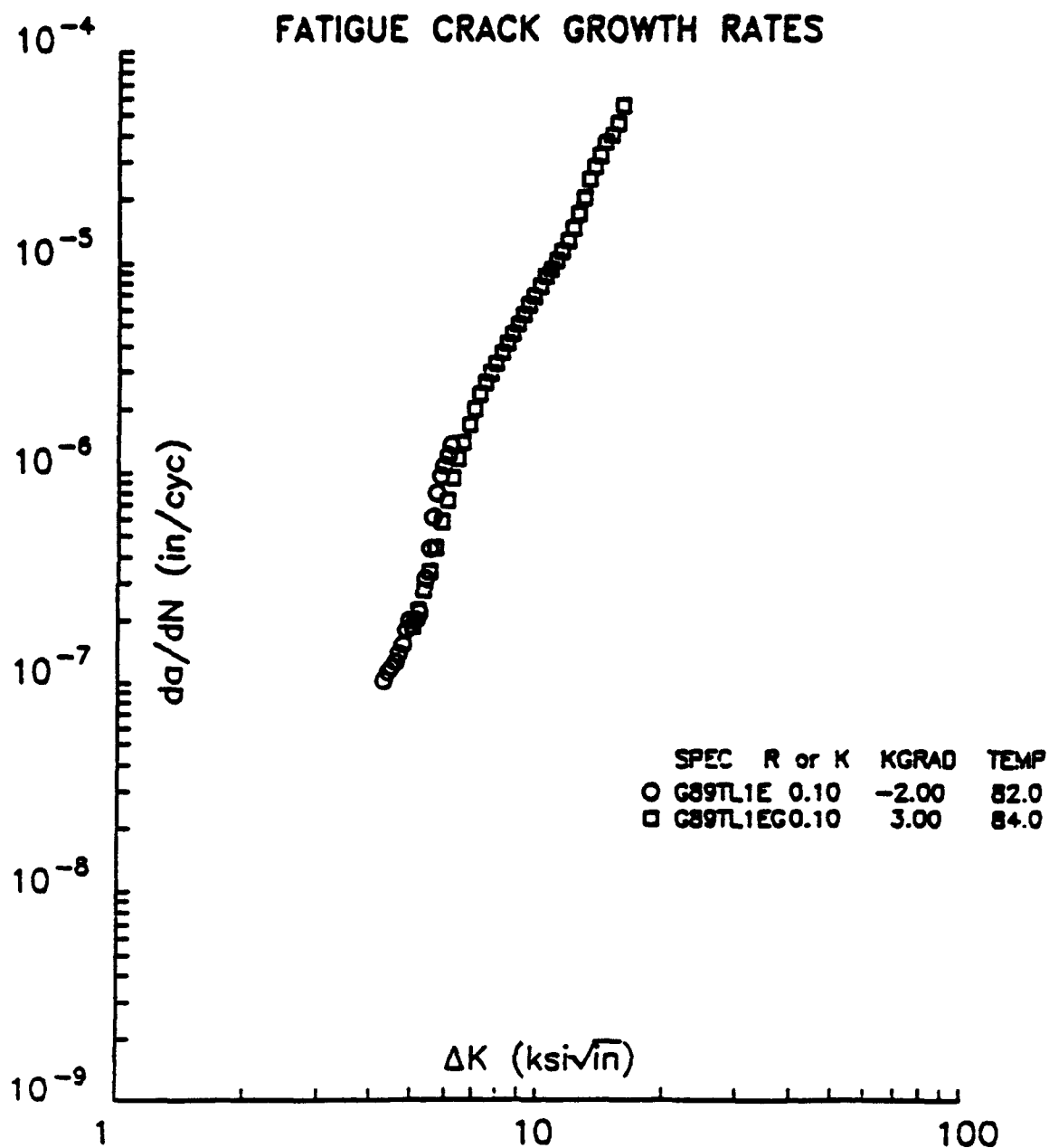


Figure E15. Fatigue Crack Growth Rate Data for Alcan 8090-T651  
1" x 4" Extrusion (T-L Orientation). NASA-Langley.

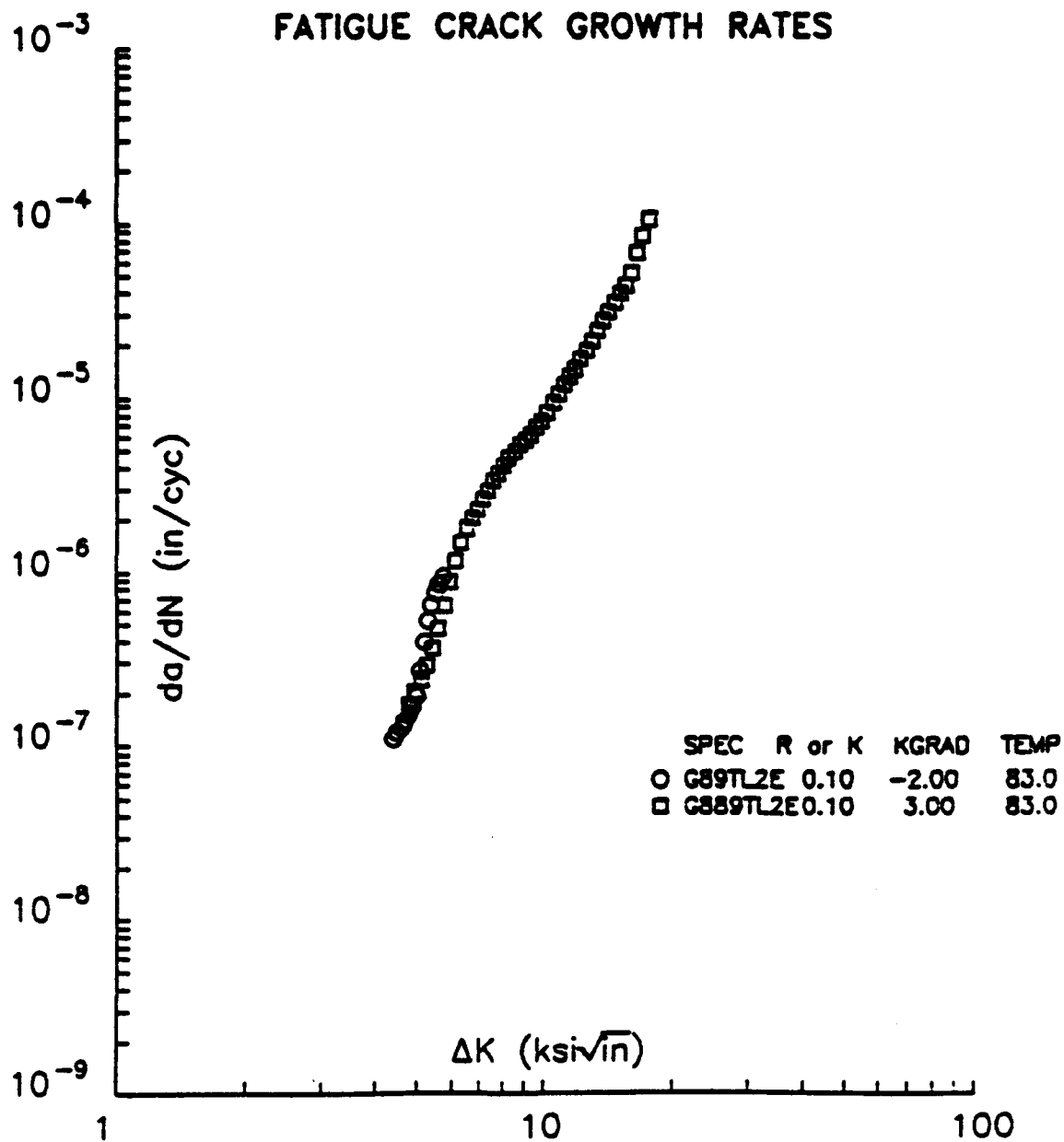


Figure E16. Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (T-L Orientation). NASA-Langley.

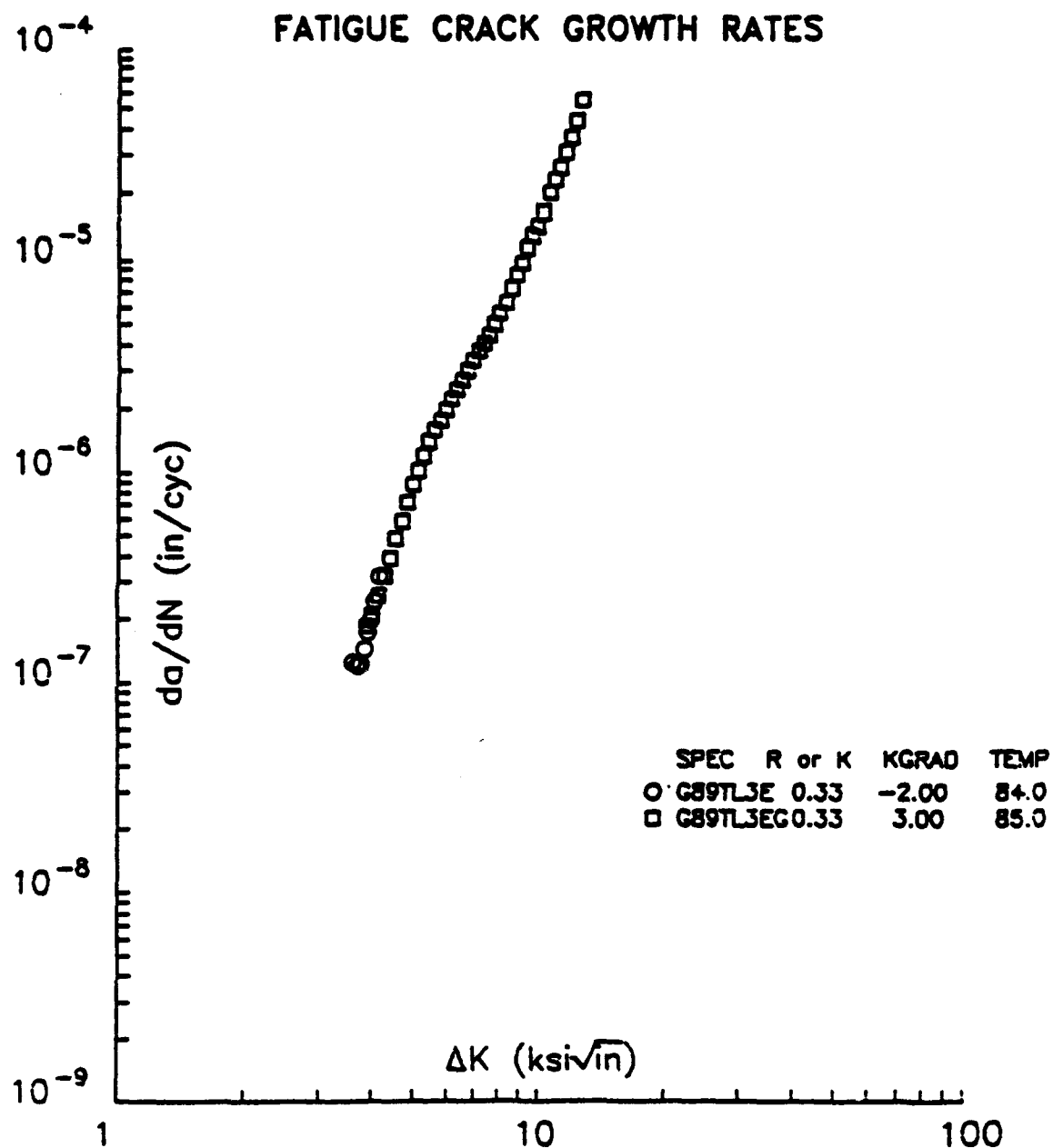


Figure E17. Fatigue Crack Growth Rate Data for Alcan 8090-T651  
1" x 4" Extrusion (T-L Orientation). NASA-Langley.

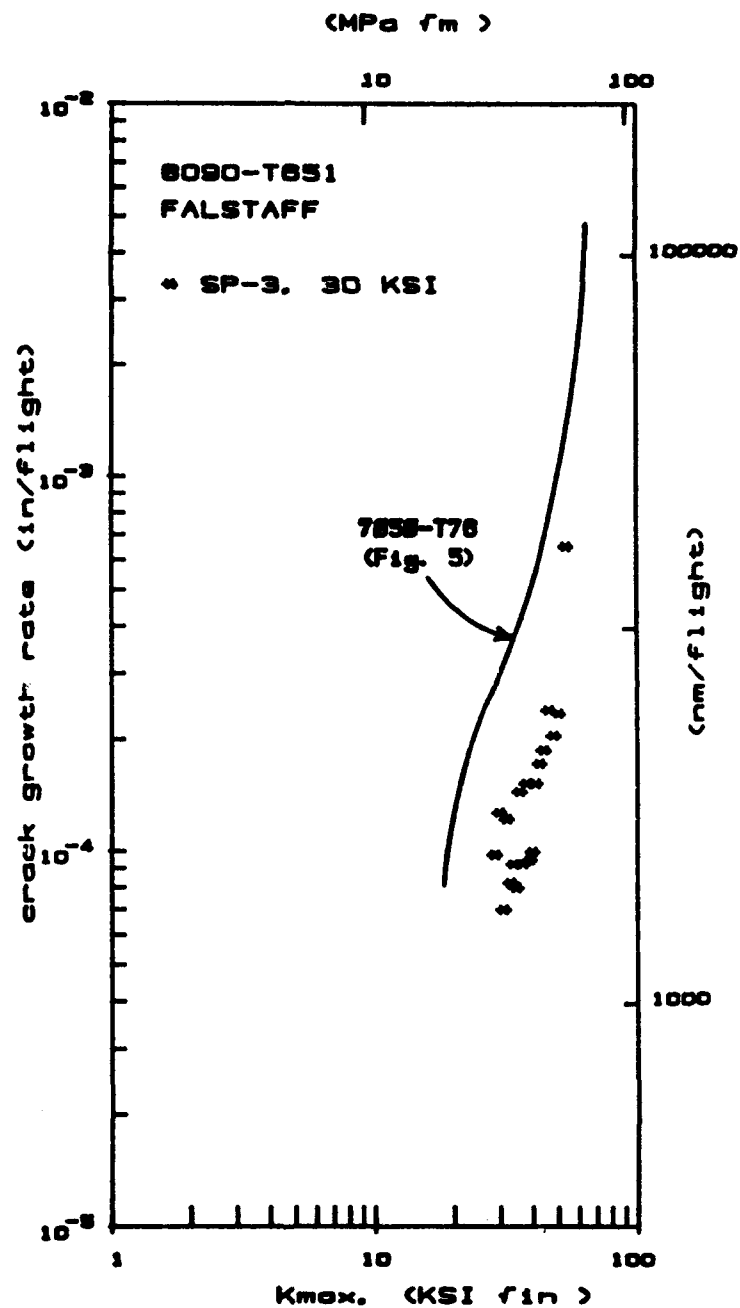


Figure E18 FALSTAFF Spectrum Results for 8090-T651 Extrusion.  
Reduced in Terms of Growth Rate and Maximum Spectrum  
Stress Intensity.

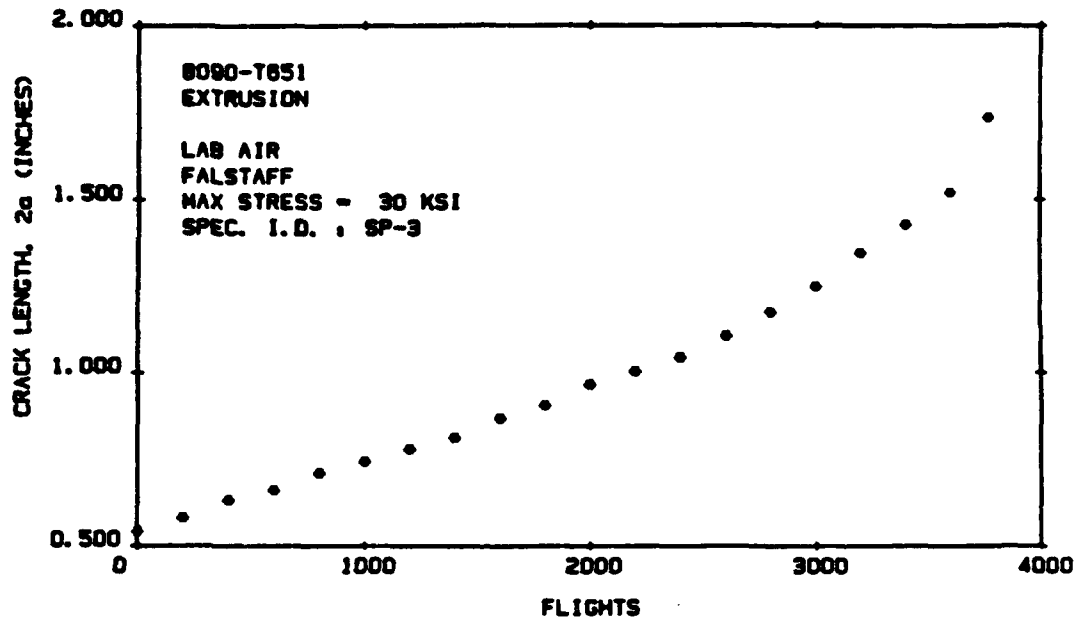


Figure E19 Crack Length Versus Flights for 8090-T651 Extrusion Under FALSTAFF Loading, Max Stress=30 KSI.

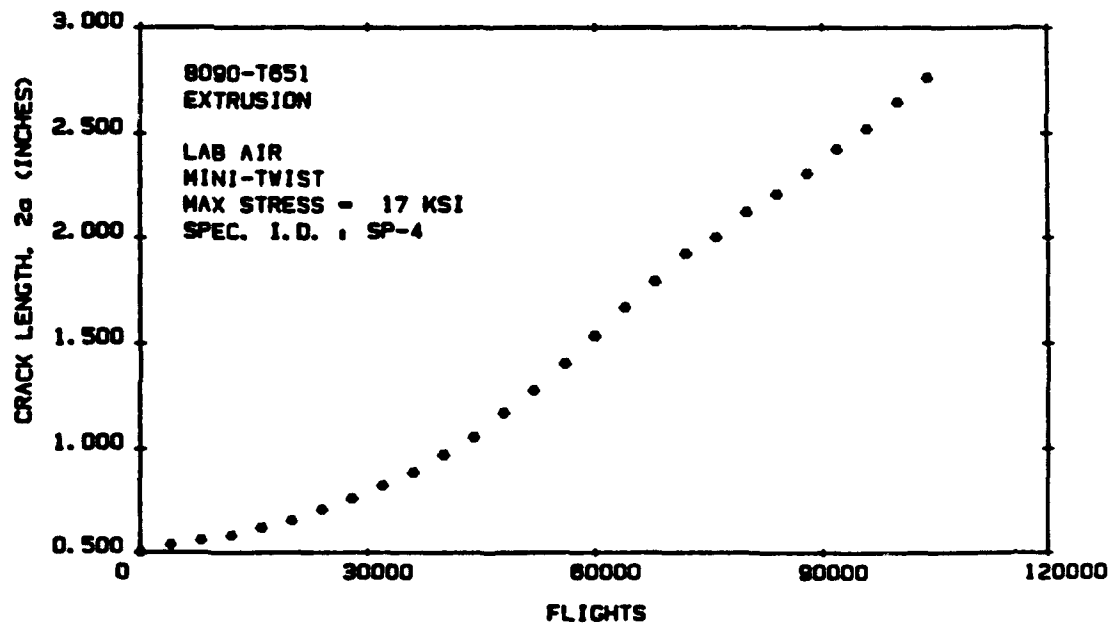


Figure E20 Crack Length Versus Flights for 8090-T651 Extrusion Under Mini-TWIST Loading, Max Stress=17 KSI.

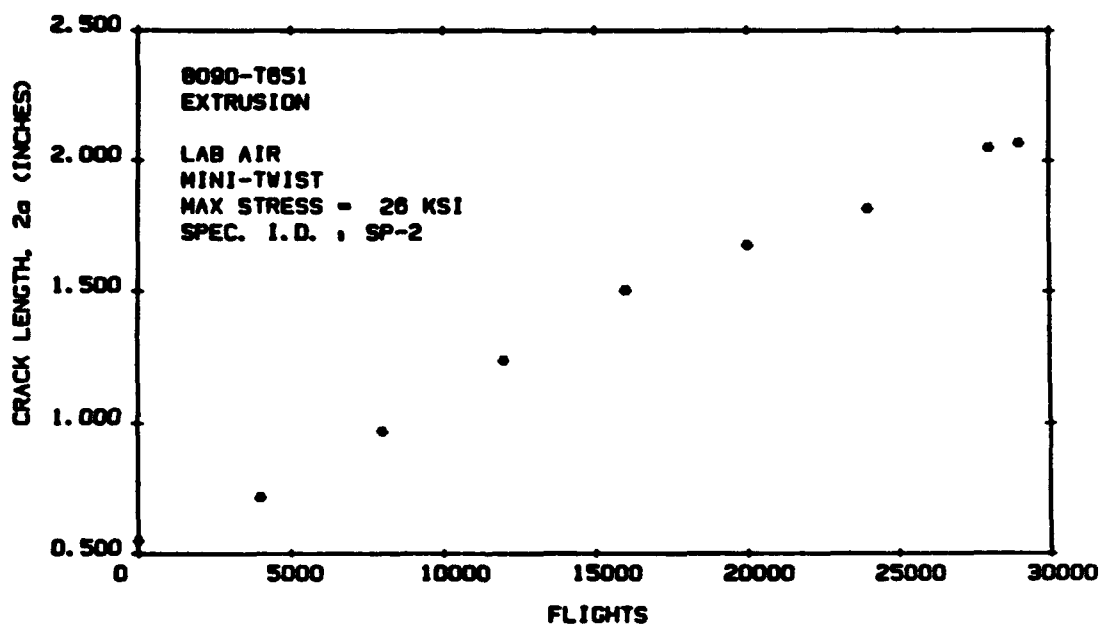


Figure E21 Crack Length Versus Flights for 8090-T651 Extrusion Under Mini-TWIST Loading, Max Stress=26 KSI.

TABLE E25

TENSILE RESULTS AT t/2 LOCATION FOR ALCAN

8090-T8 [338F FOR 24 HRS] EXTRUSION (1" x 4")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)	
GRUMMAN	RT	LONG	80.9	78.0	3.5	4.8	12.3	
			80.1	77.5	4.0	5.9	11.6	
			80.9	76.8	4.0	7.5	11.2	
		AVERAGE	80.6	77.4	3.8	6.1	11.7	
	STANDARD DEVIATION	0.5	0.6	0.3	1.4	0.6		
	GRUMMAN	RT	45	67.9	57.3	10.0	32.8	10.1
				67.6	57.6	10.0	30.4	11.4
67.1				56.2	10.0	31.2	11.2	
		AVERAGE	67.5	57.0	10.0	31.5	10.9	
STANDARD DEVIATION		0.4	0.7	0.0	1.2	0.7		
GRUMMAN	RT	L TRANS	71.9	64.0	7.5	13.4	11.8	
			70.8	62.7	7.0	18.9	11.3	
			70.5	61.6	7.0	19.4	11.1	
		AVERAGE	71.1	62.8	7.2	17.2	11.4	
	STANDARD DEVIATION	0.7	1.2	0.3	3.3	0.4		

**TABLE E26**

**COMPRESSION RESULTS FOR ALCAN**

**8090-T8 [338F FOR 24 HRS] EXTRUSION (1" x 4")**

<b>COMPANY</b>	<b>TEST TEMPERATURE (DEGREES F)</b>	<b>ORIENTATION</b>	<b>COMPRESSIVE YIELD STRENGTH (KSI)</b>	<b>COMPRESSIVE MODULUS (MSI)</b>
<b>GRUMMAN</b>	<b>RT</b>	<b>LONG</b>	<b>78.4</b>	<b>12.1</b>
			<b>77.7</b>	<b>12.1</b>
			<b>68.6</b>	<b>12.0</b>
		<b>AVERAGE</b>	<b>74.9</b>	<b>12.1</b>
		<b>STANDARD DEVIATION</b>	<b>5.5</b>	<b>0.1</b>
<b>GRUMMAN</b>	<b>RT</b>	<b>45</b>	<b>60.3</b>	<b>11.8</b>
			<b>60.3</b>	<b>11.8</b>
			<b>60.1</b>	<b>11.7</b>
		<b>AVERAGE</b>	<b>60.2</b>	<b>11.8</b>
		<b>STANDARD DEVIATION</b>	<b>0.1</b>	<b>0.1</b>
<b>GRUMMAN</b>	<b>RT</b>	<b>L TRANS</b>	<b>67.9</b>	<b>11.9</b>
			<b>67.4</b>	<b>12.1</b>
			<b>67.4</b>	<b>12.1</b>
		<b>AVERAGE</b>	<b>67.6</b>	<b>12.0</b>
		<b>STANDARD DEVIATION</b>	<b>0.3</b>	<b>0.1</b>

**TABLE E27**

**FRACTURE TOUGHNESS RESULTS FOR ALCAN**

**8090-T8 (338F FOR 24 HRS) EXTRUSION (1" x 4")**

COMPANY	ORIENTATION	K <sub>IC</sub> (KSI in <sup>0.5</sup> )	K <sub>Q</sub> (KSI in <sup>0.5</sup> )	COMMENT
GRUMMAN	L - T		33.3 INVALID(1),(2) 27.6 INVALID(2),(3)	
	AVERAGE		30.5	
	STANDARD DEVIATION		4.0	
GRUMMAN	T - L	14.6		VALID
	AVERAGE	14.6		
	STANDARD DEVIATION	0.0		

(1) 1.08 greater than B

(2) Angle of fracture greater than 5 degrees

(3) P<sub>max</sub>/P<sub>q</sub> greater than 1.10

## **APPENDIX F**

### **8090-T8771 1.75 INCH THICK PLATE**

#### **INTRODUCTION**

The Alcan aluminum-lithium alloy 8090-T8771 1.75 inch plates were received May 1991. The 8090 was tested in the as received condition by Martin Marietta and the Air Force.

#### **TESTING**

Mechanical properties (tension, compression, bearing shear and fracture toughness), fatigue and constant amplitude fatigue crack growth tests were performed according to ASTM standards, unless otherwise specified. Spectrum fatigue crack growth tests were performed by the Air Force using FALSTAFF ( a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

TABLE F1

TENSILE RESULTS AT t/2 LOCATION FOR  
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	RT	LONG	79.1	71.0	5.0	3.9	
MARIETTA			79.1	71.2	5.0	9.6	
			79.3		5.0	3.5	
AIR FORCE	RT	LONG	76.7	65.7	8.1	9.2	
			80.2	72.6	5.5	5.2	
			76.7	66.0	7.9	11.6	
		AVERAGE	78.5	69.3	6.1	7.2	
		STANDARD DEVIATION	1.5	3.2	1.5	3.4	

TABLE F2

TENSILE RESULTS AT t/2 LOCATION FOR  
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	45	72.3	54.7	11.5	17.6	
			72.4	58.0	8.9	14.5	
			72.5	55.5	9.8	15.4	
		AVERAGE	72.4	56.1	10.0	15.8	
		STANDARD DEVIATION	0.1	1.7	1.3	1.6	

TABLE F3

TENSILE RESULTS AT  $t/2$  LOCATION FOR  
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	RT	L TRANS	78.2	66.9	6.0	8.1	
MARIETTA			78.1	66.8	6.0	8.9	
			78.5	67.1	6.0	8.5	
AIR FORCE	RT	L TRANS	73.3	56.9	10.4	10.3	
			79.5	68.4	6.5	9.7	
			73.8	57.3	10.5	11.2	
		AVERAGE	76.9	63.9	7.6	9.4	
		STANDARD DEVIATION	2.7	5.3	2.2	1.2	

TABLE F4

TENSILE RESULTS AT  $t/2$  LOCATION FOR  
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	S TRANS	75.6	61.4	1.7	2.4	
			75.0	61.0	3.5	2.4	
			75.8	62.0	5.4	5.1	
		AVERAGE	75.4	61.5	3.5	3.3	
		STANDARD DEVIATION	0.4	0.5	1.8	1.6	

TABLE F5

COMPRESSION RESULTS AT  $t/2$  LOCATION FOR  
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MARTIN	RT	LONG	70.3	12.1
MARIETTA			67.0	12.1
			68.1	12.1
AIR FORCE	RT	LONG	62.5	11.8
			63.9	12.0
			60.5	10.1
		AVERAGE	65.4	11.7
		STANDARD DEVIATION	3.7	0.8

TABLE F6

COMPRESSION RESULTS AT  $t/2$  LOCATION FOR  
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MARTIN	RT	L TRANS	72.6	12.2
MARIETTA			73.6	12.0
			73.1	12.1
AIR FORCE	RT	L TRANS	62.5	11.8
			70.9	12.0
			67.5	11.9
		AVERAGE	70.0	12.0
		STANDARD DEVIATION	4.3	0.1

**TABLE F7**

**COMPRESSION RESULTS AT t/2 LOCATION FOR  
ALCAN 8090-T8771 PLATE (1.75" THICK)**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE	COMPRESSIVE
			YIELD STRENGTH (KSI)	MODULUS (KSI)
MARTIN	RT	S TRANS	69.6	12.1
MARIETTA			68.8	12.0
			68.5	12.0
		AVERAGE	69.0	12.0
		STANDARD DEVIATION	0.6	0.1

**TABLE F8**  
**ANSLER DOUBLE SHEAR RESULTS AT t/2 LOCATION FOR**  
**ALCAN 8090-T8771 PLATE (1.75" THICK)**

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
-----		
AIR FORCE	T-L	41.1
		41.8
		43.4
		44.4
		43.6
		41.4
AVERAGE		42.6
STANDARD DEVIATION		1.4

TABLE F9

BEARING RESULTS AT t/2 LOCATION FOR  
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	ORIENTATION	e/D	BEARING	BEARING
			ULT. STR. (KSI)	YIELD STR. (KSI)
AIR FORCE	LONG	1.5	112.1	90.6
			112.8	91.5
			106.9	83.7
		AVERAGE	110.6	88.6
		STANDARD DEVIATION	3.2	4.3

TABLE F10

BEARING RESULTS AT t/2 LOCATION FOR  
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	ORIENTATION	e/D	BEARING	BEARING
			ULT. STR. (KSI)	YIELD STR. (KSI)
AIR FORCE	L TRANS	1.5	109.9	89.6
			112.7	90.6
			105.7	87.3
		AVERAGE	109.4	89.2
		STANDARD DEVIATION	3.5	1.7

TABLE F11

**FRACTURE TOUGHNESS RESULTS FOR  
ALCAN 8090-T8771 PLATE (1.75" THICK)**

COMPANY	ORIENTATION	K <sub>IC</sub> (KSI in <sup>-0.5</sup> )	K <sub>q</sub> (KSI in <sup>-0.5</sup> )	COMMENT
MARTIN MARIETTA	L-T		29.9	(1)
			27.9	(1)
			28.3	(1)
AIR FORCE	L-T		24.7	(2)
			23.7	(2)
		27.0		
	AVERAGE	27.0	26.9	
	STANDARD DEVIATION	0.0	2.6	

(1): INVALID DUE TO  $a/W < 0.45$ (2): INVALID DUE TO  $P_{max}/P_q > 1.1$ 

TABLE F12

**FRACTURE TOUGHNESS RESULTS FOR  
ALCAN 8090-T8771 PLATE (1.75" THICK)**

COMPANY	ORIENTATION	K <sub>IC</sub> (KSI in <sup>-0.5</sup> )	K <sub>q</sub> (KSI in <sup>-0.5</sup> )	COMMENT
MARTIN MARIETTA	S-L		11.1	(1)
			11.0	(1)
AIR FORCE	S-L		12.1	(1)
			12.8	(1)
			9.9	(1), (2)
	AVERAGE		11.8	
	STANDARD DEVIATION		0.9	

(1): INVALID DUE TO  $K_{fat}/K_q > 0.6$ (2): INVALID DUE TO  $a, B < 2.5(K_q/Y_S)^{-2}$

TABLE F13

**FRACTURE TOUGHNESS RESULTS FOR  
ALCAN 8090-T8771 PLATE (1.75" THICK)**

COMPANY	ORIENTATION	KIC (KSI in <sup>0.5</sup> )	Kq (KSI in <sup>0.5</sup> )	COMMENT
MARTIN MARIETTA	T-L		21.0 20.1	(1) (1)
AIR FORCE	T-L	25.0 24.3 22.7		
	AVERAGE	24.0	20.6	
	STANDARD DEVIATION	1.2	0.6	

(1): INVALID DUE TO  $K_{fat}/K_q > 0.6$

TABLE F14

**FRACTURE TOUGHNESS RESULTS FOR  
ALCAN 8090-T8771 PLATE (1.75" THICK)**

COMPANY	ORIENTATION	KIC (KSI in <sup>0.5</sup> )	Kq (KSI in <sup>0.5</sup> )	COMMENT
MARTIN MARIETTA	S-T		13.1	(1)
	AVERAGE		13.1	
	STANDARD DEVIATION		0.0	

(1): INVALID DUE TO  $K_{fat}/K_q > 0.6$

TABLE F15

FATIGUE RESULTS WITH  $R=0.1$  AND  $K_t=1.0$  FOR  
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
AIR FORCE	LONG	73.5	5,016
		69.0	15,020
		66.0	16,366
		60.0	36,998
		57.0	93,383
		50.8	280,000
		48.0	95,642
		43.5	2,946,918
		37.5	17,000,000 *
		29.0	10,000,000 *

(\*): RUN OUT

TABLE F16

FATIGUE RESULTS WITH  $R=0.1$  AND  $K_t=3.0$  FOR  
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
AIR FORCE	LONG	50.0	3,822
		40.0	7,994
		30.0	32,103
		28.0	39,796
		26.0	74,224
		24.0	64,517
		22.0	135,951
		21.0	648,867
		20.5	103,502
		20.0	10,000,000 *

(\*): RUN OUT

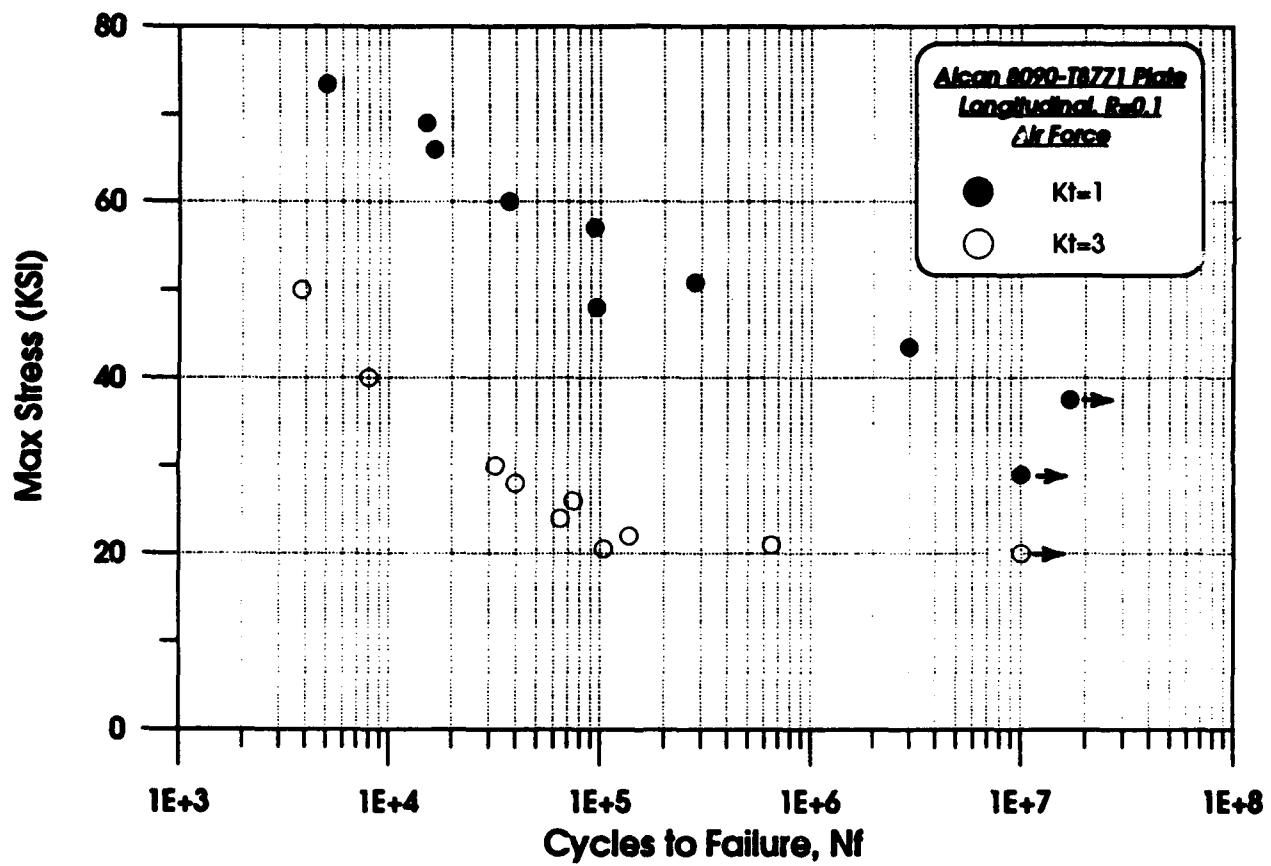


FIGURE F1. Fatigue Results for 8090-T8771 Plate (Longitudinal Orientation).  
Air Force.

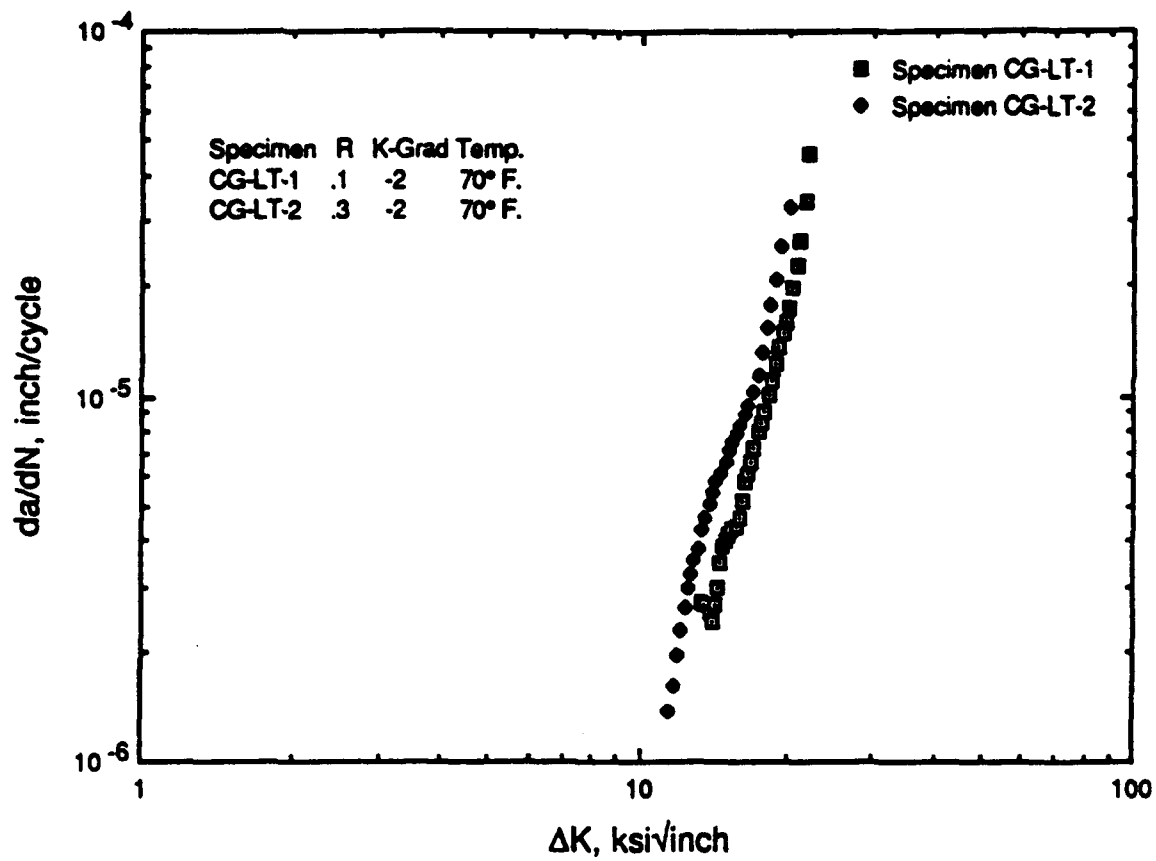


FIGURE F2. Fatigue Crack Growth Rate Data for 8090-T8771 Plate (L-T Orientation).  
 Martin Marietta.

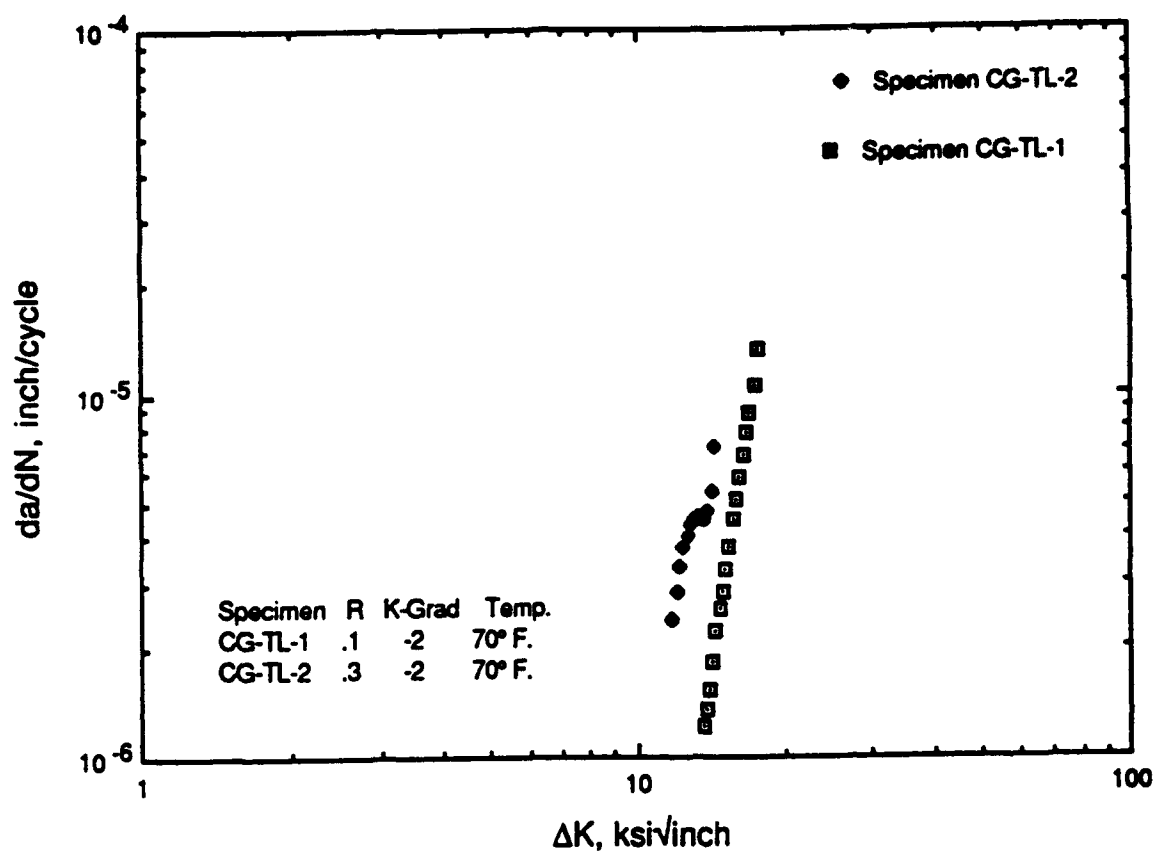


FIGURE F3. Fatigue Crack Growth Rate Data for 8090-T8771 Plate (T-L Orientation).  
Martin Marietta.

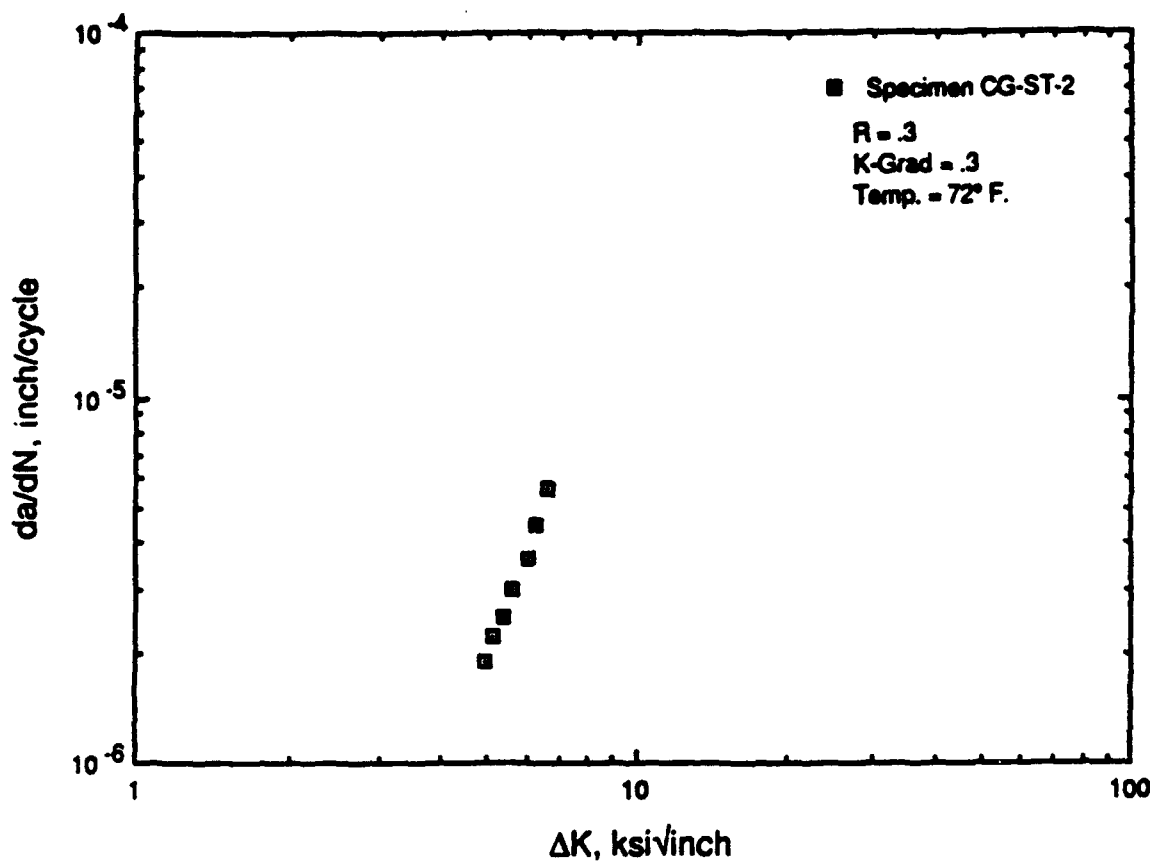


FIGURE F4. Fatigue Crack Growth Rate Data for 8090-T8771 Plate (S-T Orientation).  
Martin Marietta.

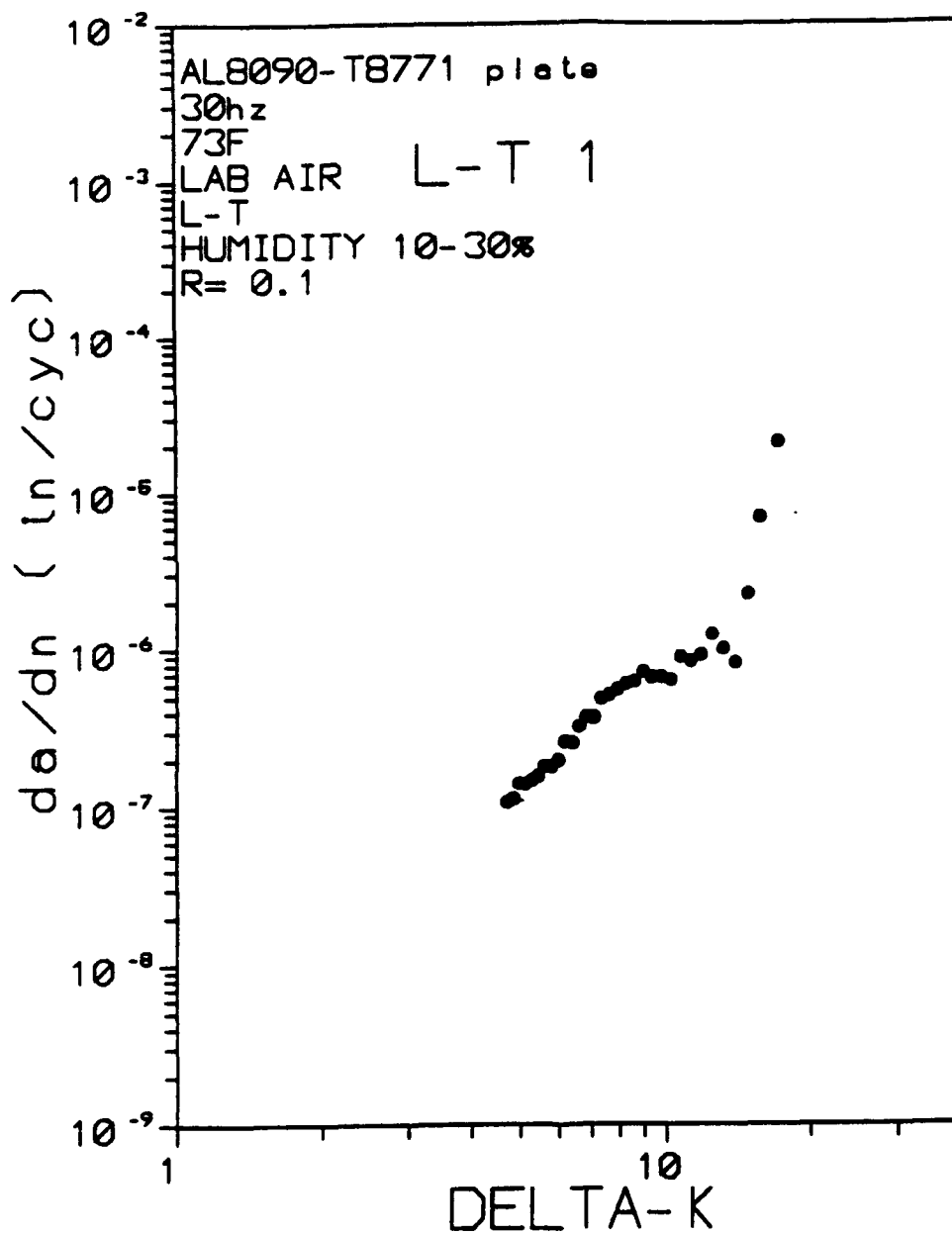


FIGURE F5. Fatigue Crack Growth Rate Data for 8090-T8771 Plate (L-T Orientation and R=0.1).  
 Air Force.

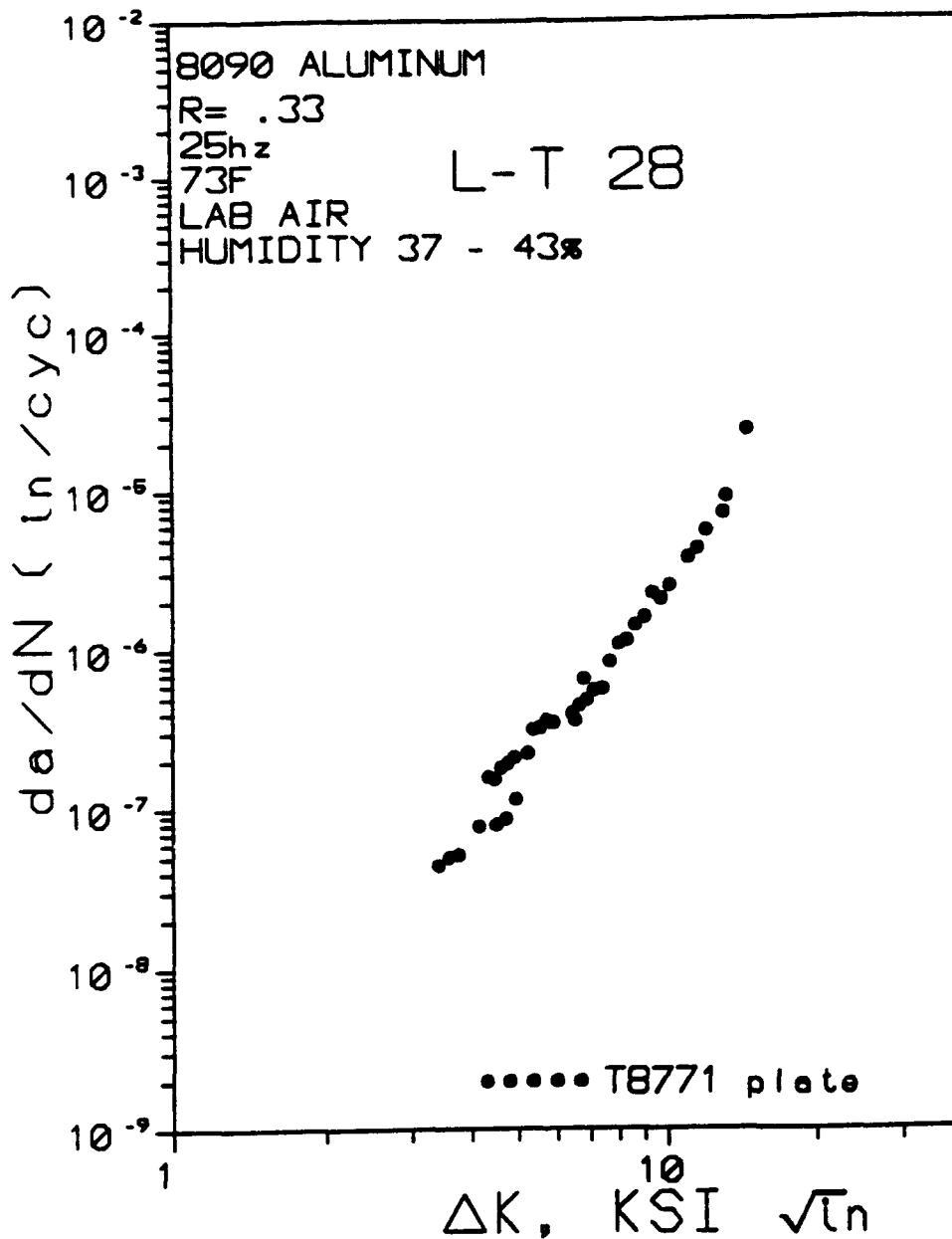


FIGURE F6. Fatigue Crack Growth Rate Data for 8090-T8771 Plate (L-T Orientation and R=0.33). Air Force.

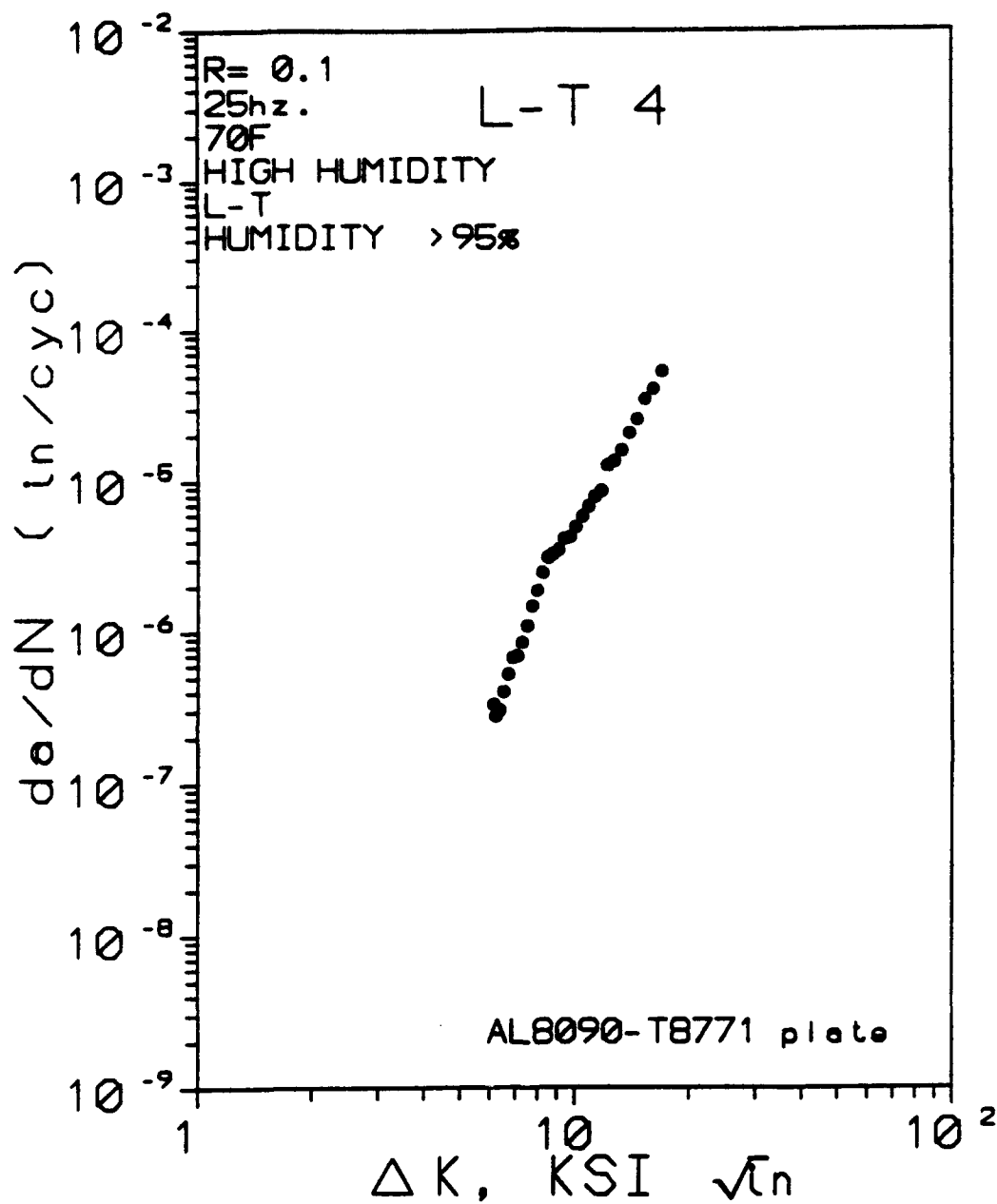


FIGURE F7. Fatigue Crack Growth Rate Data for 8090-T8771 Plate (L-T Orientation and  $R=0.1$  and High Humidity). Air Force.

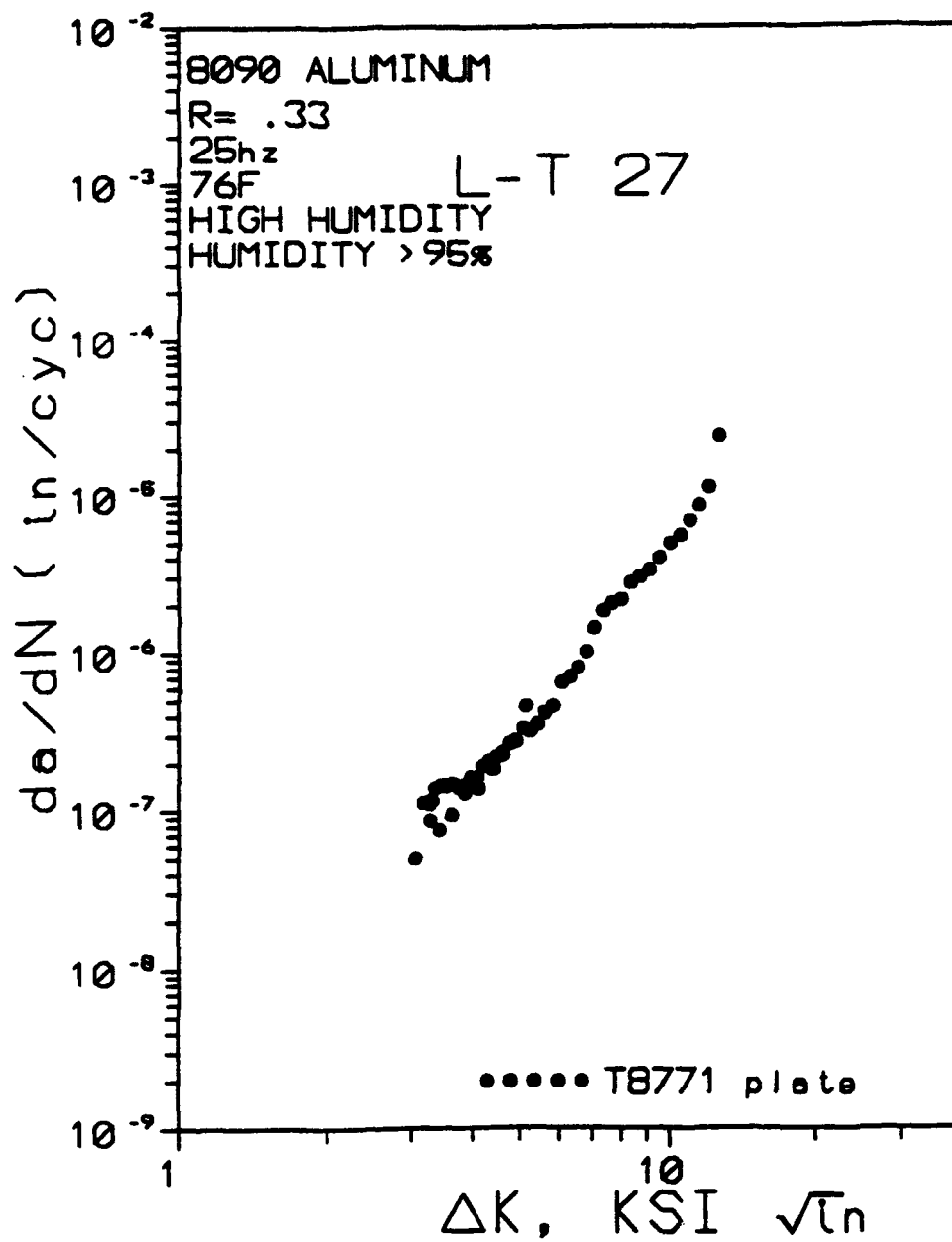


FIGURE F8. Fatigue Crack Growth Rate Data for 8090-T8771 Plate (L-T Orientation and R=0.33 and High Humidity). Air Force.

# MINI-TWIST 16.9 KSI

AL8090 PL-2

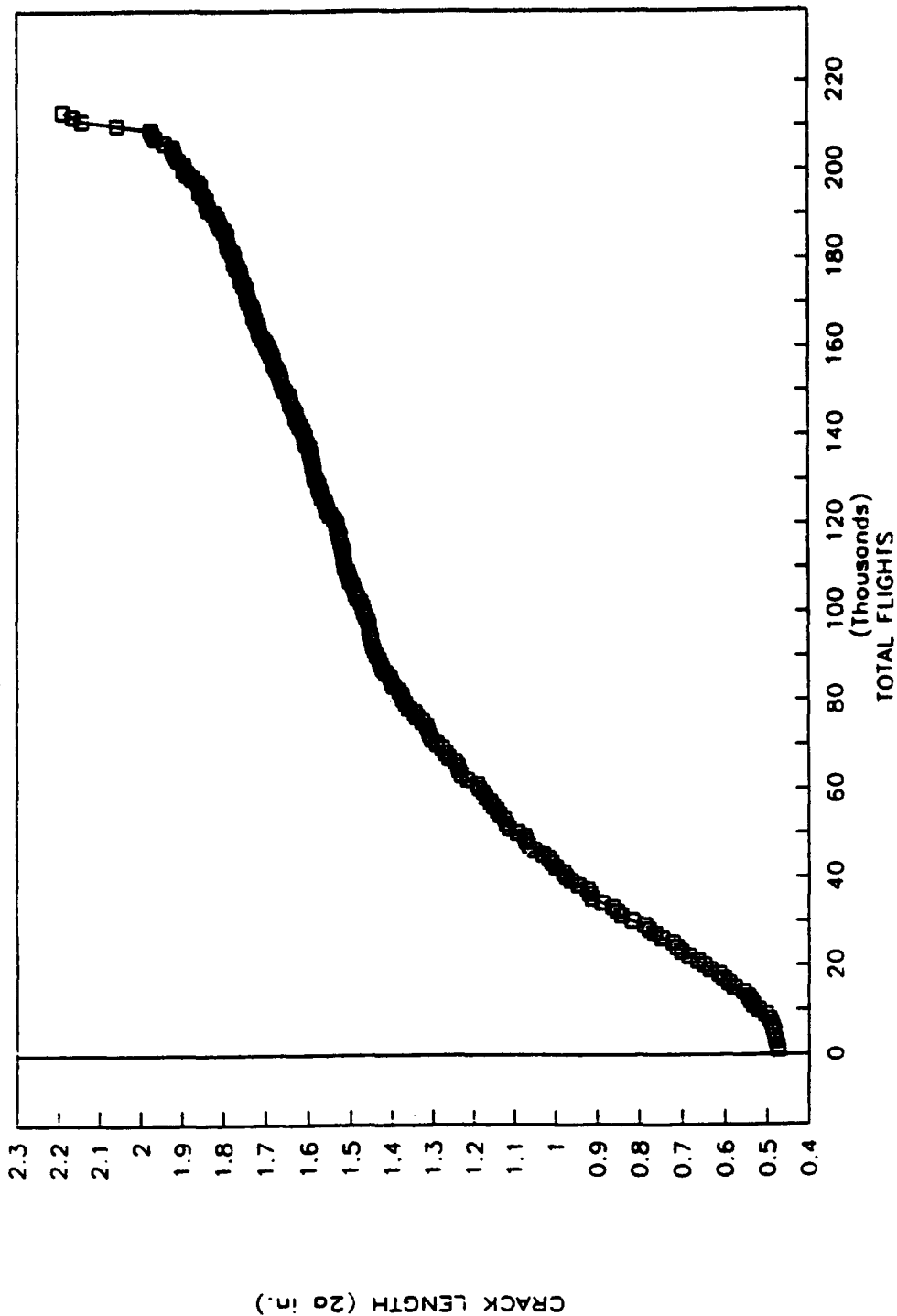


FIGURE F9. Mini-TWIST Spectrum Crack Length vs Flights Data for 8090-T8771 Plate (L-T Orientation, Room Temperature, Lab Air and Maximum Stress = 16.9 Ksi). Air Force.

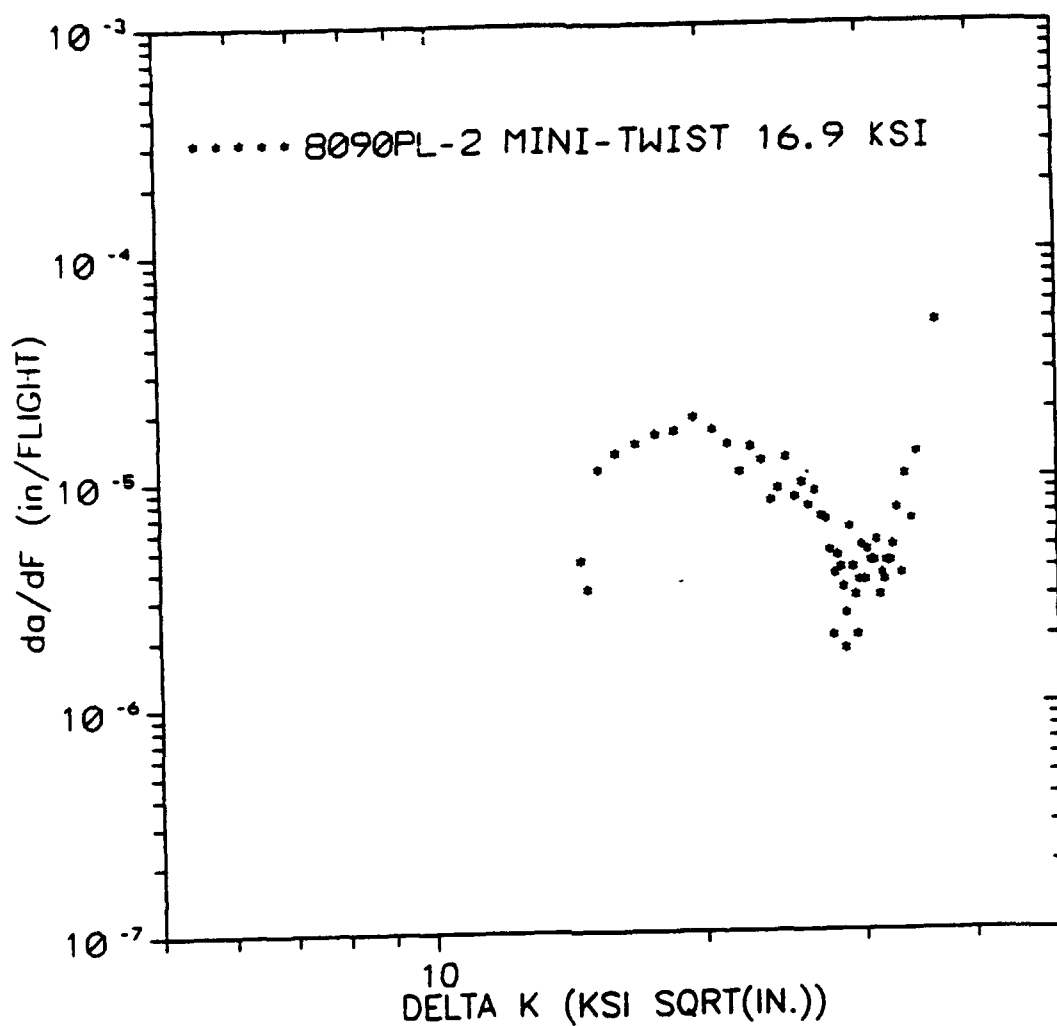


FIGURE F10. Mini-TWIST Spectrum Crack Growth Rate vs Delta K Data for 8090-T8771 Plate (L-T Orientation, Room Temperature, Lab Air and Maximum Stress = 16.9 KSU). Air Force.

8090PL1

FALSTAFF 20 KSI

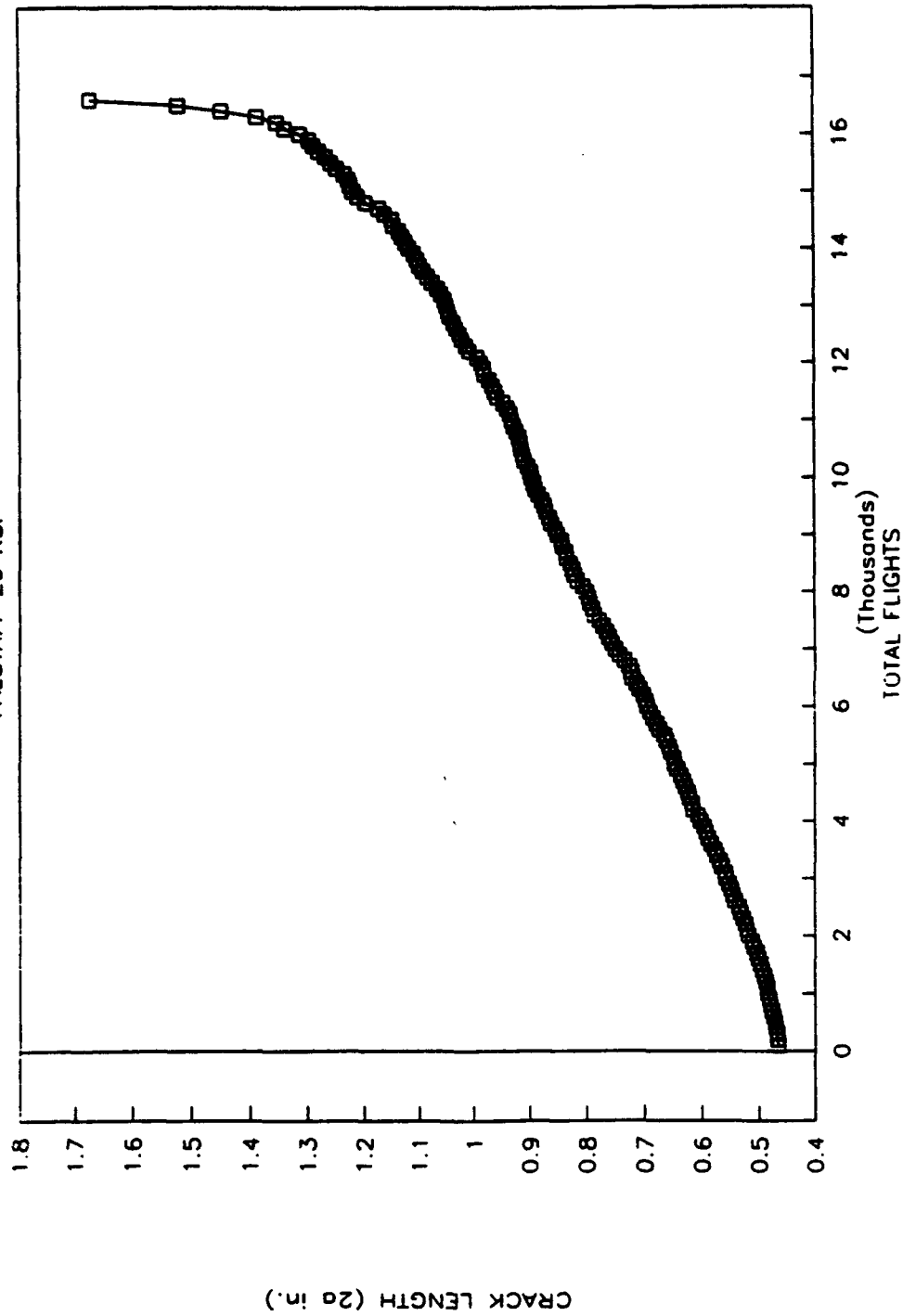
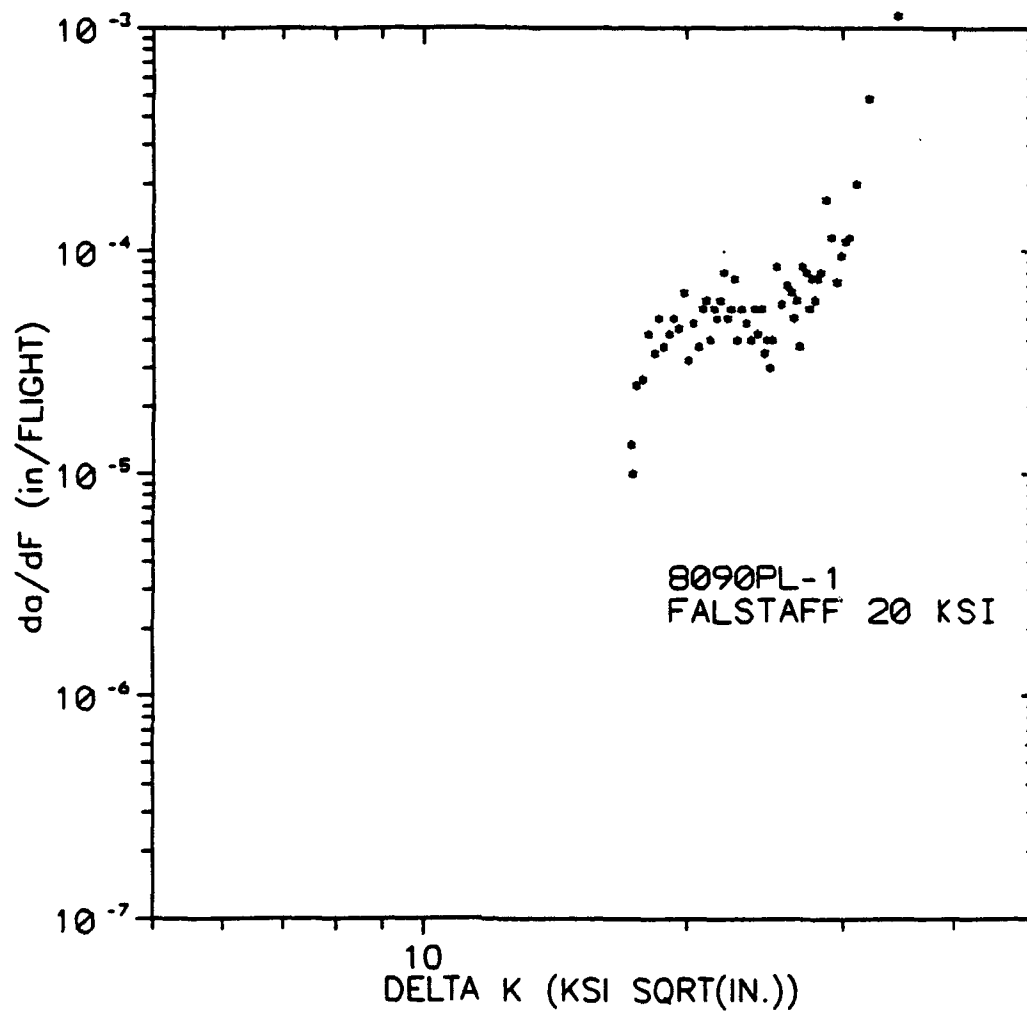


FIGURE F11. FALSTAFF Spectrum Crack Length vs Total Flights Data for 8090-T8771 Plate (L-T Orientation, Room Temperature, Lab Air and Maximum Stress = 20 Ksi). Air Force.



**FIGURE F12. FALSTAFF Spectrum Crack Growth Rate vs Delta K Data for 8090-T8771 Plate (L-T Orientation, Room Temperature, Lab Air and Maximum Stress = 20 Ksi). Air Force.**

## **APPENDIX G**

### **IN905XL PRECISION FORGING**

#### **INTRODUCTION**

The IN905XL Forgings were produced in a pilot plant under developmental conditions in 1986. Significant variability in properties can be expected under such conditions.

The IN905XL forgings were received the first quarter of 1987 and all the participants except General Dynamics TX tested the material in the as-received condition. General Dynamics TX exposed the forging to a two-step solution treatment and aging. Figure G1 shows the geometry of the IN905XL jack fitting precision forging.

#### **TESTING**

Basic mechanical properties (tension, compression, bearing, etc) were tested according to ASTM standards, unless otherwise specified.

Constant amplitude fatigue crack growth tests were conducted according to ASTM E647 standard. Northrop Corporation and General Dynamics performed constant amplitude fatigue crack growth test using K controlled methods. McDonnell Aircraft Company (MCAIR) used a WOL specimen geometry.

A mini-TWIST (moderately intense fatigue environment) spectrum test was performed by the Air Force.

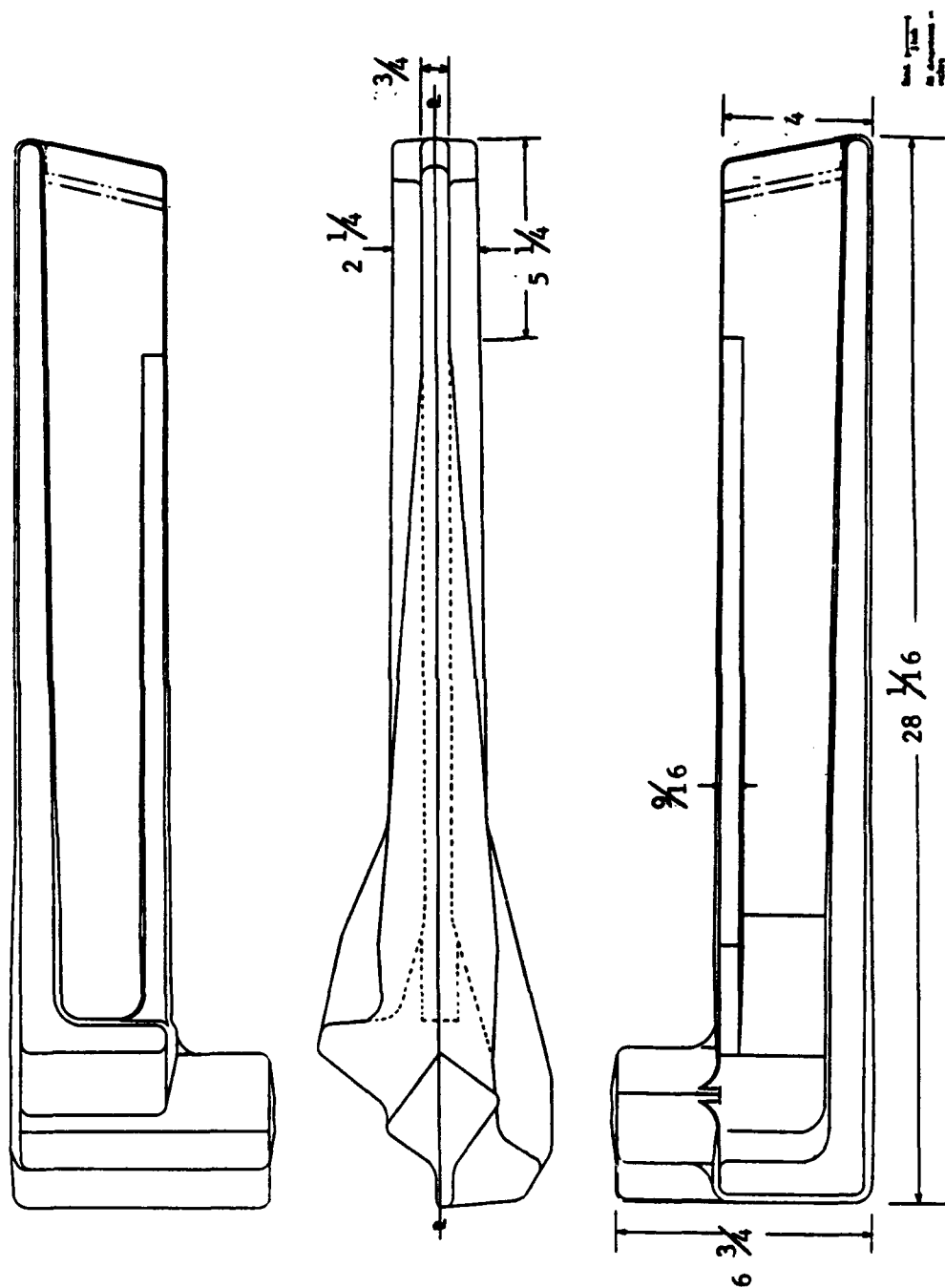


Figure G1 IN905XL Jack Fitting Precision Forcing

TABLE G1  
TENSILE RESULTS FOR  
IN905XL FORGING

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)	COMMENT
AIR FORCE	RT	LONG	66.6	52.0	11.5	23.0		(1)
			65.9	50.6	11.9	21.0		(1)
			66.1	52.0	11.8	25.0		(1)
			64.3	51.6	13.6	27.6		(2)
			63.7	48.7	10.4	12.4		(2)
			62.7	49.5	11.0	19.4		(2)
			67.7	56.0	13.0	30.3		(1)
			68.0	56.1	13.0	25.3		(1)
			68.3	57.7	13.0	28.0		(1)
MCAIR	RT	LONG	75.0	65.0	9.0	18.2	11.6	(1)
			75.5	64.5	8.0	15.6	11.9	(1)
			74.5	62.0	9.0	20.3	12.4	(1)
LTV	RT	LONG	68.0	51.5	13.0	21.6	10.8	(1)
			67.9	54.8	12.0	17.4	10.8	(1)
			64.7	50.2	11.0	9.2	10.8	(1)
NORTHROP	RT	LONG	67.4	55.4	10.0		11.6	(1)
				55.7			12.1	(1)
			67.0	55.3	12.0		12.2	(1)
			64.3	53.9	12.0		11.5	(2)
			65.0	53.3	11.0		11.9	(2)
			64.7	51.7	12.0		11.3	(2)
MARTIN MARIETTA	RT	LONG	75.1	62.2	12.0	13.9	11.4	
			75.9	63.8	10.0	14.7	11.4	
			78.1	64.9	10.0	13.2	11.6	
SIKORSKY	RT	LONG	67.5	57.7	7.5		12.4	(1)
			67.8	55.9	14.0		12.2	(1)
			68.0	55.3	13.0		12.6	(1)
			67.8	54.7	13.0		12.1	(1)
			68.9	57.0	13.0		12.7	(1)
			68.5	56.1	14.0		12.0	(1)
NASA LANGLEY	RT	LONG	67.0	57.3	7.0		11.5	
			67.9	57.8	9.0		11.4	
			67.6	58.1	7.0		11.5	
AVERAGE			68.4	56.0	11.2	19.8	11.7	
STANDARD DEVIATION			3.9	4.5	2.0	6.0	0.5	

(1): THIN SECTION (WEB/FLANGE SECTION)  
(2): THICK SECTION (END SECTION)

**TABLE G2**  
**TENSILE RESULTS FOR**  
**IN905XL FORGING**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)	COMMENT
AIR FORCE	RT	L TRANS	66.9	54.1	9.3	16.8		(1)
			67.2	53.9	7.0	11.7		(1)
			67.8	54.7	8.0	15.8		(1)
			64.9	51.2	13.3	19.9		(2)
			64.4	50.4	11.1	19.0		(2)
			64.4	49.7	9.3	13.5		(2)
			64.8	50.9	9.0	18.3		(1)
			64.1	50.1	11.0	12.3		(1)
			63.5	49.5	8.0	17.6		(1)
MCAIR	RT	L TRANS	74.5	66.0	8.0	15.1	12.4	(1)
			74.5	61.5	9.0	18.5	12.6	(1)
			74.5	64.5	8.0	16.3	11.5	(1)
LTV	RT	L TRANS	66.8	55.2	10.0	19.2	11.2	(1)
			67.0	54.7	10.0	18.6	11.5	(1)
			67.4	55.2	12.0	17.7	11.2	(1)
NORTHROP	RT	L TRANS	66.3	54.9	10.0		11.6	(1)
			65.8	54.3	11.0		11.5	(1)
			66.6	54.9	12.5		11.6	(1)
			64.8	51.4	6.0		11.9	(2)
			65.0	52.5	8.0		11.7	(2)
			65.3	52.9	8.0		11.9	(2)
MARTIN MARIETTA	RT	L TRANS	69.5	54.9	4.0	1.6	11.3	
			69.8	54.8	3.0	1.6	11.1	
			69.3	54.6	4.0	3.2	11.0	
SIKORSKY	RT	L TRANS	68.1	56.7	14.0		12.7	(1)
			67.9	56.8	10.0		11.8	(1)
			69.0	57.8	13.0		13.5	(1)
			68.7	58.1	9.0		11.1	(1)
NASA LANGLEY	RT	L TRANS	67.9	58.1	8.0		11.5	
			67.8	58.4	8.0		11.4	
			68.0	58.4	8.0		11.5	
AVERAGE			67.5	55.2	9.0	14.3	11.7	
STANDARD DEVIATION			2.9	4.0	2.6	6.1	0.6	

(1): THIN SECTION (WEB/FLANGE SECTION)  
(2): THICK SECTION (END SECTION)

TABLE G3  
TENSILE RESULTS FOR  
IN905XL FORGING

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)	COMMENT
LTV	RT	S TRANS	64.7	50.8	8.0	7.7	11.2	(2)
			67.3	54.8	12.0	28.4	10.9	(2)
			63.2	50.8	8.0	10.3	11.2	(2)
NORTHROP	RT	S TRANS	64.1	52.6	6.5		11.4	(1)
			64.3	52.2	8.0		12.1	(1)
			64.7	51.5	8.0		11.9	(1)
MARTIN MARIETTA	RT	S TRANS	74.1	61.2	6.0	4.8	11.6	
			75.5	62.0	6.0	4.0	11.3	
			72.6	60.8	4.0	4.8	11.2	
SIKORSKY	RT	S TRANS	67.7	54.8	9.0		11.6	(1)
			65.3	50.8	5.0		12.8	(1)
NASA LANGLEY	RT	S TRANS	63.9	53.3	5.0		11.2	
			63.1	53.7	5.0		11.4	
			63.8	53.6	5.0		11.3	
AVERAGE			66.7	54.5	6.8	10.0	11.5	
STANDARD DEVIATION			4.2	4.0	2.1	9.3	0.5	

(1): THIN SECTION (WEB/FLANGE SECTION)

(2): THICK SECTION (END SECTION)

**TABLE G4**  
**TENSILE RESULTS FOR**  
**IN905XL FORGING**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)	COMMENT
GENERAL DYNAMICS	RT	LONG	69.7	57.6				*
			67.1	59.2	9.7		*	
		AVERAGE	68.4	58.4	9.7			
		STANDARD DEVIATION	1.8	1.1				

(\*): THIN SECTION

NOTE: HEAT TREATED WITH THE FOLLOWING SCHEDULE:

- STEP 1 - 850F FOR 2 HRS
- STEP 2 - 665F FOR 2 HRS
- STEP 3 - WARM WATER QUENCH
- STEP 4 - 230F FOR 24 HRS

**TABLE G5**  
**TENSILE RESULTS FOR**  
**IN905XL FORGING**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)	COMMENT
GENERAL DYNAMICS	RT	L TRANS	71.2	58.7	8.6			*
			67.9	56.6	9.7			*
		AVERAGE		69.6	57.7	9.2		
		STANDARD DEVIATION		2.3	1.5	0.8		

(\*): THIN SECTION

NOTE: HEAT TREATED WITH THE FOLLOWING SCHEDULE:

- STEP 1 - 850F FOR 2 HRS
- STEP 2 - 665F FOR 2 HRS
- STEP 3 - WARM WATER QUENCH
- STEP 4 - 230F FOR 24 HRS

**TABLE G6**  
**COMPRESSION RESULTS FOR**  
**IN905XL FORGING**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCAIR	RT	LONG	65.9	11.9
			65.9	10.4
			65.6	11.8
LTV	RT	LONG	59.1	11.9
			53.3	12.1
			60.5	12.0
NORTHROP	RT	LONG	56.6	11.7
			57.1	12.2
			57.4	12.0
MARTIN MARIETTA	RT	LONG	70.3	12.4
			70.9	12.3
			71.0	12.3
SIKORSKY	RT	LONG	57.9	13.2
			56.6	11.2
NASA LANGLEY	RT	LONG	60.7	11.7
			61.4	11.7
			61.6	11.7
AVERAGE			61.9	11.9
STANDARD DEVIATION			5.5	0.6

NOTE: NORTHROP SPECIMENS TAKEN FROM WEB/FLANGE SECTION.

**TABLE G7**  
**COMPRESSION RESULTS FOR**  
**IN905XL FORGING**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCAIR	RT	L TRANS	64.2	12.1
			62.5	12.4
			62.0	12.7
LTV	RT	L TRANS	57.3	11.5
			58.9	12.3
			56.5	12.2
NORTHROP	RT	L TRANS	56.2	11.9
			56.0	11.8
			56.0	11.9
MARTIN MARIETTA	RT	L TRANS	67.2	12.3
			67.2	12.2
			67.3	12.3
SIKORSKY	RT	L TRANS	56.2	12.5
			55.5	11.8
			55.4	12.4
NASA LANGLEY	RT	L TRANS	59.3	11.7
			59.2	11.6
			59.2	11.7
AVERAGE			59.8	12.1
STANDARD DEVIATION			4.3	0.3

**NOTE: NORTHROP SPECIMENS TAKEN FROM WEB/FLANGE SECTION.**

**TABLE G8**  
**COMPRESSION RESULTS FOR**  
**IN905XL FORGING**

<b>COMPANY</b>	<b>TEST TEMPERATURE (DEGREES F)</b>	<b>ORIENTATION</b>	<b>COMPRESSIVE YIELD STRENGTH (KSI)</b>	<b>COMPRESSIVE MODULUS (MSI)</b>
<b>LTV</b>	<b>RT</b>	<b>S TRANS</b>	<b>54.1</b>	<b>11.5</b>
			<b>59.3</b>	<b>12.0</b>
			<b>53.7</b>	<b>11.8</b>
<b>NORTHROP</b>	<b>RT</b>	<b>S TRANS</b>	<b>50.8</b>	<b>11.9</b>
			<b>51.1</b>	<b>11.9</b>
			<b>50.1</b>	<b>11.8</b>
<b>MARTIN MARIETTA</b>	<b>RT</b>	<b>S TRANS</b>	<b>57.1</b>	<b>12.2</b>
			<b>57.1</b>	<b>12.1</b>
			<b>56.5</b>	<b>12.0</b>
<b>NASA LANGLEY</b>	<b>RT</b>	<b>S TRANS</b>	<b>56.5</b>	<b>11.6</b>
			<b>AVERAGE</b>	<b>11.9</b>
			<b>STANDARD DEVIATION</b>	<b>0.2</b>

**NOTE: NORTHROP SPECIMENS TAKEN FROM WEB/FLANGE SECTION.**

**TABLE G9**  
**COMPRESSION RESULTS FOR**  
**IN905XL FORGING**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
GENERAL DYNAMICS (*)	RT	LONG	58.0	11.4

(\*): HEAT TREATED TO THE FOLLOWING SCHEDULE:  
 STEP 1 - 850F FOR 2 HRS  
 STEP 2 - 665F FOR 2 HRS  
 STEP 3 - WARM WATER QUENCH  
 STEP 4 - 230F FOR 24 HRS

**TABLE G10**  
**COMPRESSION RESULTS FOR**  
**IN905XL FORGING**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
GENERAL DYNAMICS (*)	RT	L TRANS	59.3 55.9	11.7 11.7
AVERAGE			57.6	11.7
STANDARD DEVIATION			2.4	0.0

(\*): HEAT TREATED TO THE FOLLOWING SCHEDULE:  
 STEP 1 - 850F FOR 2 HRS  
 STEP 2 - 665F FOR 2 HRS  
 STEP 3 - WARM WATER QUENCH  
 STEP 4 - 230F FOR 24 HRS

**TABLE G11**  
**IOSIPESCU SHEAR RESULTS FOR**  
**IN905XL FORGING**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<hr/>		
<b>LTV</b>	<b>LONG</b>	<b>41.8</b>
		<b>41.7</b>
	<b>AVERAGE</b>	<b>41.8</b>
	<b>STANDARD DEVIATION</b>	<b>0.1</b>

**TABLE G12**  
**IOSIPESCU SHEAR RESULTS FOR**  
**IN905XL FORGING**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<hr/>		
<b>LTV</b>	<b>L TRANS</b>	<b>40.4</b>
		<b>41.4</b>
		<b>41.7</b>
		<b>41.1</b>
	<b>AVERAGE</b>	<b>41.2</b>
	<b>STANDARD DEVIATION</b>	<b>0</b>

**TABLE G13**  
**AMSLER DOUBLE SHEAR RESULTS FOR**  
**IN905XL FORGING**

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
<hr/>		
GENERAL DYNAMICS (*)	L - S	37.7
		37.9
	AVERAGE	37.8
	STANDARD DEVIATION	0.1

(\*): HEAT TREATED TO THE FOLLOWING SCHEDULE:  
 STEP 1 - 850F FOR 2 HRS  
 STEP 2 - 665F FOR 2 HRS  
 STEP 3 - WARM WATER QUENCH  
 STEP 4 - 230F FOR 24 HRS

**TABLE G14**  
**AMSLER DOUBLE SHEAR RESULTS FOR**  
**IN905XL FORGING**

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
<hr/>		
NORTHROP	L - S	39.6
		39.3
		39.3
NASA-LANGLEY	L - S	41.0
		40.9
		40.7
	AVERAGE	40.1
	STANDARD DEVIATION	0.8

**TABLE G15**  
**AMSLER DOUBLE SHEAR RESULTS FOR**  
**IN905XL FORGING**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<hr/>		
<b>NASA-LANGLEY</b>	<b>T - S</b>	<b>40.9</b>
		<b>41.0</b>
		<b>40.7</b>
	<b>AVERAGE</b>	<b>40.9</b>
	<b>STANDARD DEVIATION</b>	<b>0.2</b>

**TABLE G16**  
**SLOTTED SHEAR RESULTS FOR**  
**IN905XL FORGING**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<hr/>		
<b>MCAIR</b>	<b>LONG</b>	<b>44.5</b>
		<b>41.5</b>
		<b>38.0</b>
	<b>AVERAGE</b>	<b>41.3</b>
	<b>STANDARD DEVIATION</b>	<b>3.3</b>

**TABLE G17**  
**BEARING RESULTS FOR**  
**IN905XL FORGING**

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
LTV	LONG	1.5		97.0		82.5
				95.9		83.7
NORTHROP	LONG	1.5		102.0		83.9
				89.4		77.7
				100.8		82.3
NASA-LANGLEY	LONG	1.5		88.4		79.3
				92.6		78.7
AVERAGE				97.0		82.0
STANDARD DEVIATION				5.0		2.5

NOTE: NORTHROP SPECIMENS TAKEN FROM WEB/FLANGE SECTION.

**TABLE G18**  
**BEARING RESULTS FOR**  
**IN905XL FORGING**

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
LTV	L TRANS	1.5		118.0		91.5
				115.0		97.9
NORTHROP	L TRANS	1.5		85.3		77.3
				98.1		82.3
				86.7		77.2
AVERAGE				100.6		85.2
STANDARD DEVIATION				15.4		9.2

NOTE: NORTHROP SPECIMENS TAKEN FROM WEB/FLANGE SECTION.

**TABLE G19**  
**BEARING RESULTS FOR**  
**IN905XL FORGING**

COMPANY	ORIENTATION	e/D	BEARING		BEARING
			ULT.	STR.	YIELD STR.
			(KSI)		(KSI)
MCAIR	LONG	2.0	125.0		104.0
			125.0		107.0
			124.0		102.0
LTV	LONG	2.0	118.0		91.5
			115.0		97.9
NORTHROP	LONG	2.0	125.1		96.5
			125.9		95.7
			125.9		93.7
AVERAGE			123.0		98.5
STANDARD DEVIATION			4.1		5.3

**TABLE G20**  
**BEARING RESULTS FOR**  
**IN905XL FORGING**

COMPANY	ORIENTATION	e/D	BEARING		BEARING
			ULT.	STR.	YIELD STR.
			(KSI)		(KSI)
GENERAL DYNAMICS	LONG	2.0	111.0		93.4
			113.3		92.9
		AVERAGE	112.2		93.2
		STANDARD DEVIATION	1.6		0.4

(\*): HEAT TREATED TO THE FOLLOWING SCHEDULE:  
 STEP 1 - 850F FOR 2 HRS  
 STEP 2 - 665F FOR 2 HRS  
 STEP 3 - WARM WATER QUENCH  
 STEP 4 - 230F FOR 24 HRS

TABLE G21  
BEARING RESULTS FOR  
IN905XL FORGING

COMPANY	ORIENTATION	e/D	BEARING		BEARING
			ULT.	STR.	YIELD STR.
			(KSI)		(KSI)
MCAIR	L TRANS	2.0		105.0	101.0
				123.0	103.0
				122.0	103.0
LTV	L TRANS	2.0		117.2	100.5
				124.7	97.3
NORTHROP	L TRANS	2.0		117.5	89.0
				124.2	92.2
				115.7	89.0
		AVERAGE		118.7	96.9
		STANDARD DEVIATION		6.5	6.0

TABLE G22  
BEARING RESULTS FOR  
IN905XL FORGING

COMPANY	ORIENTATION	e/D	BEARING		BEARING
			ULT.	STR.	YIELD
			(KSI)		(KSI)
GENERAL DYNAMICS	L TRANS	2.0		108.4	89.3
			(*)	107.9	90.4
AVERAGE				108.2	89.9
STANDARD DEVIATION				0.4	0.8

(\*): HEAT TREATED TO THE FOLLOWING SCHEDULE:

STEP 1 - 850F FOR 2 HRS  
STEP 2 - 665F FOR 2 HRS  
STEP 3 - WARM WATER QUENCH  
STEP 4 - 230F FOR 24 HRS

TABLE G23  
FRACTURE TOUGHNESS RESULTS FOR  
IN905XL FORGING

COMPANY	ORIENTATION	KIC (KSI in <sup>0.5</sup> )	Kq (KSI in <sup>0.5</sup> )	COMMENT
MCAIR	L-T	18.8 24.9		VALID VALID
NORTHROP	L-T		37.9 38.3	(1) (1)
MARTIN MARIETTA	L-T		27.7	(2)
AVERAGE		21.9	34.6	
STANDARD DEVIATION		4.3	6.0	

(1): INVALID DUE TO  $P_{max}/P_q > 1.10$

(2): INVALID DUE TO PRE-CRACK GROWTH  $> 0.55W$

NOTE: NORTHROP SPECIMENS TAKEN FROM END SECTION.

TABLE G24  
FRACTURE TOUGHNESS RESULTS FOR  
IN905XL FORGING

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
<hr/>				
MCAIR	T-L	23.5		VALID
		21.0		VALID
LTV	T-L		33.9	(1)
			35.4	(1)
			31.5	(1)
			33.4	(1)
NORTHROP	T-L		34.4	(1)
			33.4	(1)
MARTIN MARIETTA	T-L		22.8	(2)
			21.7	(2)
AVERAGE		22.3	30.8	
STANDARD DEVIATION		1.7	5.4	

(1): INVALID DUE TO  $F_{max}/P_q > 1.10$

(2): INVALID DUE TO PRE-CRACK GROWTH  $> 0.55W$

NOTE: NORTHROP SPECIMENS TAKEN FROM END SECTION.

TABLE G25  
FRACTURE TOUGHNESS RESULTS FOR  
IN905XL FORGING

COMPANY	ORIENTATION	KIC	Kq	COMMENT
		(KSI in^0.5)	(KSI in^0.5)	
<hr/>				
LTV	T-S		34.1	(1)
			33.3	(1)
	AVERAGE		33.7	
	STANDARD DEVIATION		0.6	

(1): INVALID DUE TO  $P_{max}/P_q > 1.10$

TABLE G26  
FRACTURE TOUGHNESS RESULTS FOR  
IN905XL FORGING

COMPANY	ORIENTATION	KIC (KSI in <sup>0.5</sup> )	Kq (KSI in <sup>0.5</sup> )	COMMENT
MCAIR	S-T	17.8 19.3		VALID VALID
MARTIN MARIETTA	S-T	15.6 16.3		
			15.0	(1)
	AVERAGE	17.2	15.0	
	STANDARD DEVIATION	1.6		

(1): INVALID DUE TO PRE-CRACK GROWTH > 0.55W

TABLE G27  
FRACTURE TOUGHNESS RESULTS FOR  
IN905XL FORGING

COMPANY	ORIENTATION	KIC (KSI in <sup>0.5</sup> )	Kq (KSI in <sup>0.5</sup> )	COMMENT
MARTIN MARIETTA	S-L	19.5		VALID
			19.1 23.8	(1) (2)
	AVERAGE	19.5	21.5	
	STANDARD DEVIATION		3.3	

(1): INVALID DUE TO ASSYMETRIC CRACK GROWTH

(2): INVALID DUE TO PRE-CRACK GROWTH > 0.55W

**TABLE G28**  
**FRACTURE TOUGHNESS RESULTS FOR**  
**IN905XL FORGING**

COMPANY	ORIENTATION	KIC	Kq	COMMENT
		(KSI in <sup>0.5</sup> )	(KSI in <sup>0.5</sup> )	
GENERAL DYNAMICS	L-T		32.4	(1), (2)
			35.1	(1), (2)
	AVERAGE		33.8	
	STANDARD DEVIATION		1.9	

- (1): SPECIMEN THICKNESS LESS THAN REQUIRED FOR VALIDITY  
(2): HEAT TREATED TO THE FOLLOWING SCHEDULE:  
STEP 1 - 850F FOR 2 HRS  
STEP 2 - 665F FOR 2 HRS  
STEP 3 - WARM WATER QUENCH  
STEP 4 - 230F FOR 24 HRS

**TABLE G29**  
**FRACTURE TOUGHNESS RESULTS FOR**  
**IN905XL FORGING**

COMPANY	ORIENTATION	KIC	Kq	COMMENT
		(KSI in <sup>0.5</sup> )	(KSI in <sup>0.5</sup> )	
GENERAL DYNAMICS	T-L		29.8	(1), (2)
			30.7	(1), (2)
	AVERAGE		30.3	
	STANDARD DEVIATION		0.6	

- (1): SPECIMEN THICKNESS LESS THAN REQUIRED FOR VALIDITY  
(2): HEAT TREATED TO THE FOLLOWING SCHEDULE:  
STEP 1 - 850F FOR 2 HRS  
STEP 2 - 665F FOR 2 HRS  
STEP 3 - WARM WATER QUENCH

# Novamet IN905XL Forging

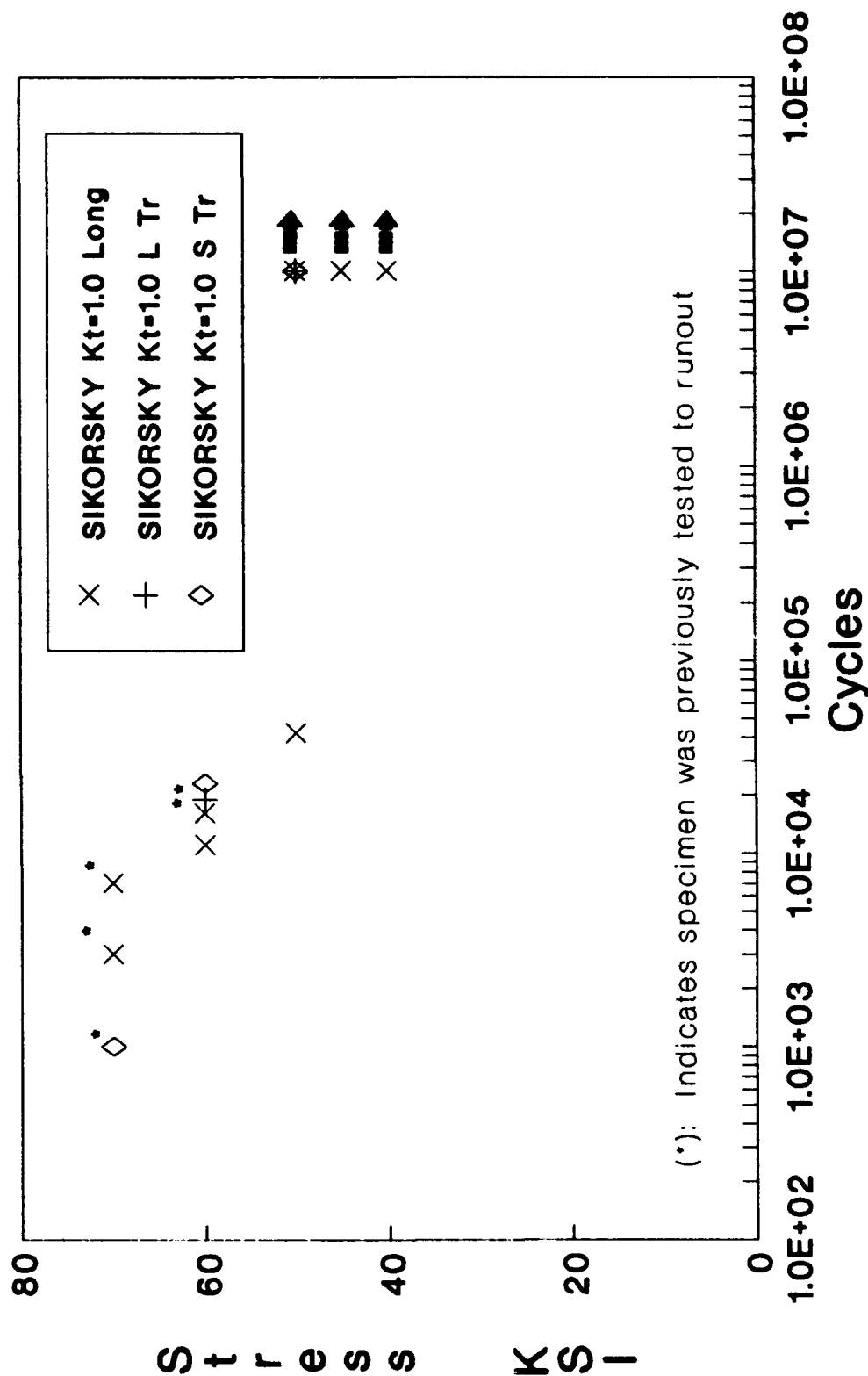


Figure G2 Fatigue Results for IN905XL Forging (R=0.1, Kt=1.0). Sikorsky.

**TABLE G30**  
**FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR**  
**IN905XL FORGING**

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
<hr/>			
SIKORSKY	LONG	70.0	3,000 #
		70.0	7,000 !
		60.0	16,000 &
		60.0	11,000
		50.0	42,000
		50.0	10,000,000 *
		45.0	10,000,000 *
		40.0	10,000,000 *

(\*): INDICATES A RUNOUT TEST

(#): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 40 KSI

(!): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 50 KSI

(&): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 45 KSI

**TABLE G31**  
**FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR**  
**IN905XL FORGING**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>STRESS (KSI)</b>	<b>CYCLES</b>
<hr/>			
<b>SIKORSKY</b>	<b>L TRANS</b>	<b>60.0</b>	<b>19,000 #</b>
		<b>50.0</b>	<b>10,000,000 *</b>

**(\*) : INDICATES A RUNOUT TEST**

**(#) : INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 50 KSI**

**TABLE G32**  
**FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR**  
**IN905XL FORGING**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>STRESS (KSI)</b>	<b>CYCLES</b>
<hr/>			
<b>SIKORSKY</b>	<b>S TRANS</b>	<b>70.0</b>	<b>1,000 #</b>
		<b>60.0</b>	<b>23,000</b>
		<b>50.0</b>	<b>10,000,000 *</b>

**(\*)**: INDICATES A RUNOUT TEST

**(#)**: INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 50 KSI

# Novamet IN905XL Forging

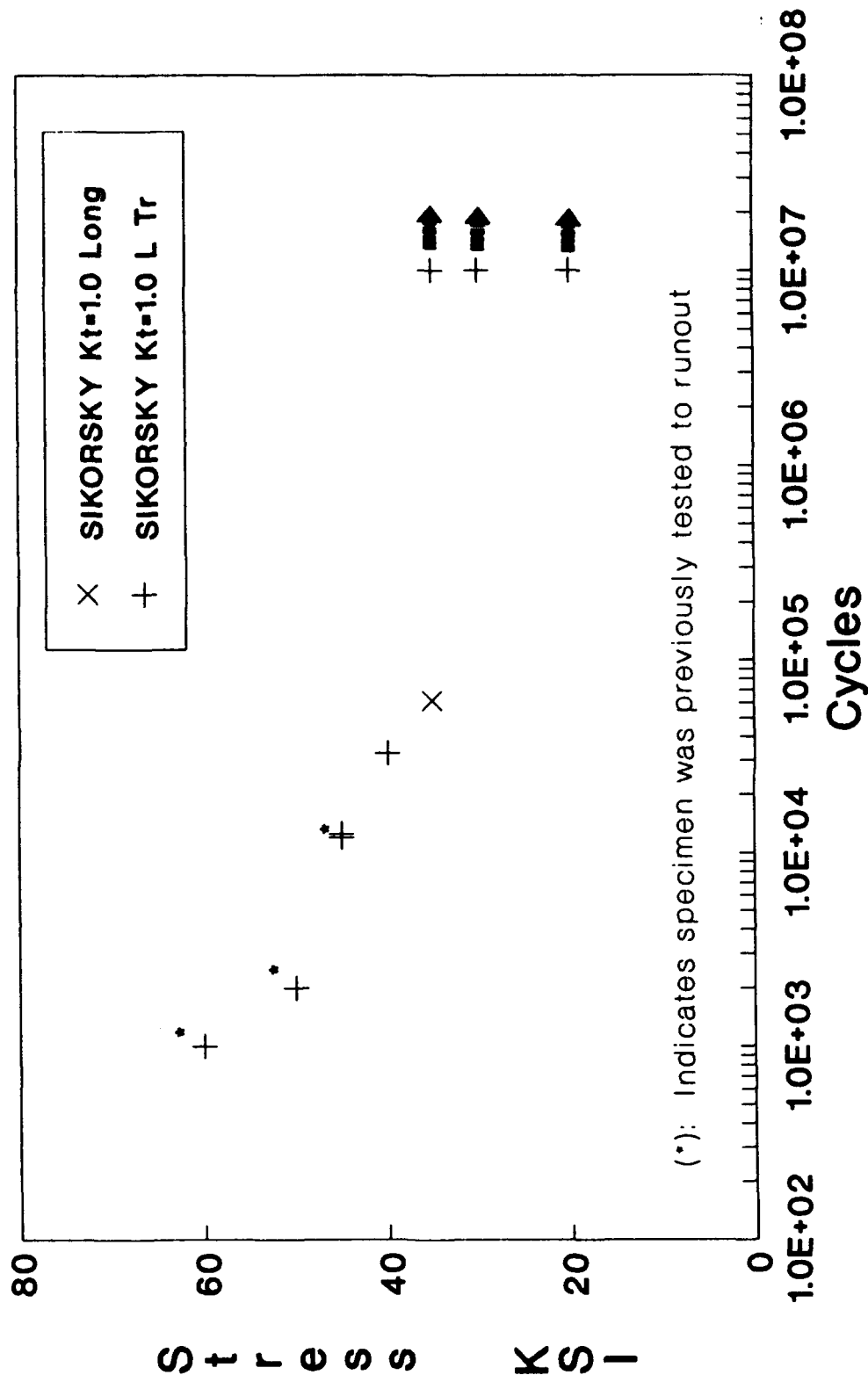


Figure C3 Fatigue Results for IN905XL Forging ( $R=-1.0$ ,  $K_t=1.0$ ). Sikorsky.

TABLE G33  
 FATIGUE RESULTS WITH R=-1.0 AND Kt=1.0 FOR  
 IN905XL FORGING

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
<hr/>			
SIKORSKY	LONG	35.0	61,200

**TABLE G34**  
**FATIGUE RESULTS WITH R=-1.0 AND Kt=1.0 FOR**  
**IN905XL FORGING**

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
<hr/>			
SIKORSKY	L TRANS	60.0	1,000 #
		50.0	2,000 !
		45.0	12,500
		45.0	12,000 &
		40.0	32,500
		35.0	10,000,000 *
		30.0	10,000,000 *
		20.0	10,000,000 *

(\*): INDICATES A RUNOUT TEST

(#): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 30 KSI

(!): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 20 KSI

(&): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 35 KSI

# Novamet IN905XL Forging

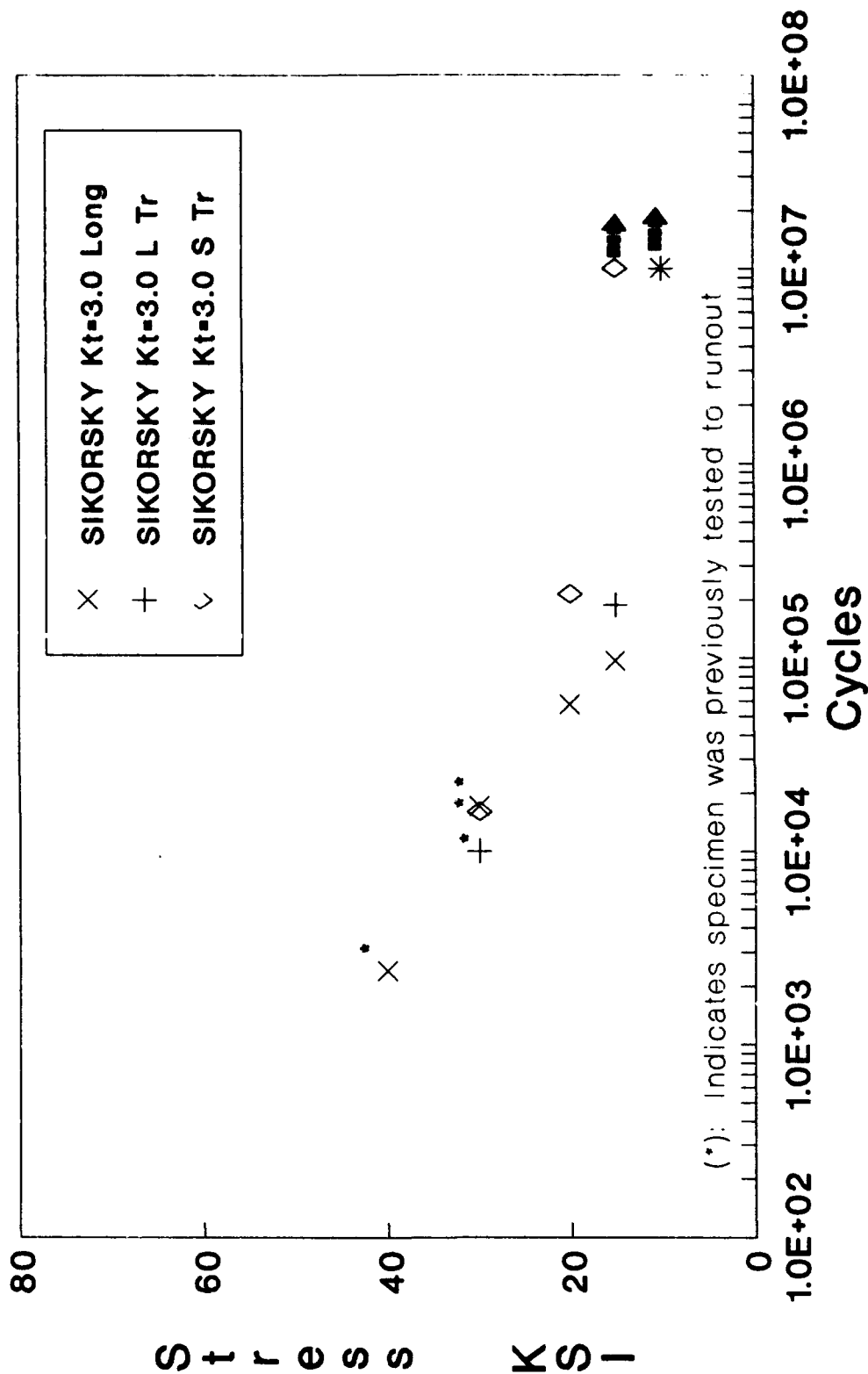


Figure C4 Fatigue Results for IN905XL Forging (R=0.1, Kt=3.0). Sikorsky.

TABLE G35  
FATIGUE RESULTS WITH R=0.1 AND Kt=3.07 FOR  
IN905XL FORGING

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
<hr/>			
SIKORSKY	LONG	40.0	2,400 #
		30.0	17,000 #
		20.0	57,000
		15.0	96,000
		10.0	10,000,000 *
		10.0	10,000,000 *

(\*): INDICATES A RUNOUT TEST

(#): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 10 KSI

TABLE G36  
FATIGUE RESULTS WITH R=0.1 AND Kt=3.07 FOR  
IN905XL FORGING

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
<hr/>			
SIKORSKY	L TRANS	30.0	10,000 #
		15.0	187,400
		10.0	10,000,000 *

(\*): INDICATES A RUNOUT TEST

(#): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 10 KSI

TABLE G37  
FATIGUE RESULTS WITH R=0.1 AND Kt=3.07 FOR  
IN905XL FORGING

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
<hr/>			
SIKORSKY	S TRANS	30.0	16,000 #
		20.0	213,400
		15.0	10,000,000 *

(\*): INDICATES A RUNOUT TEST

(#): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 15 KSI

# Novamet IN905XL Forging

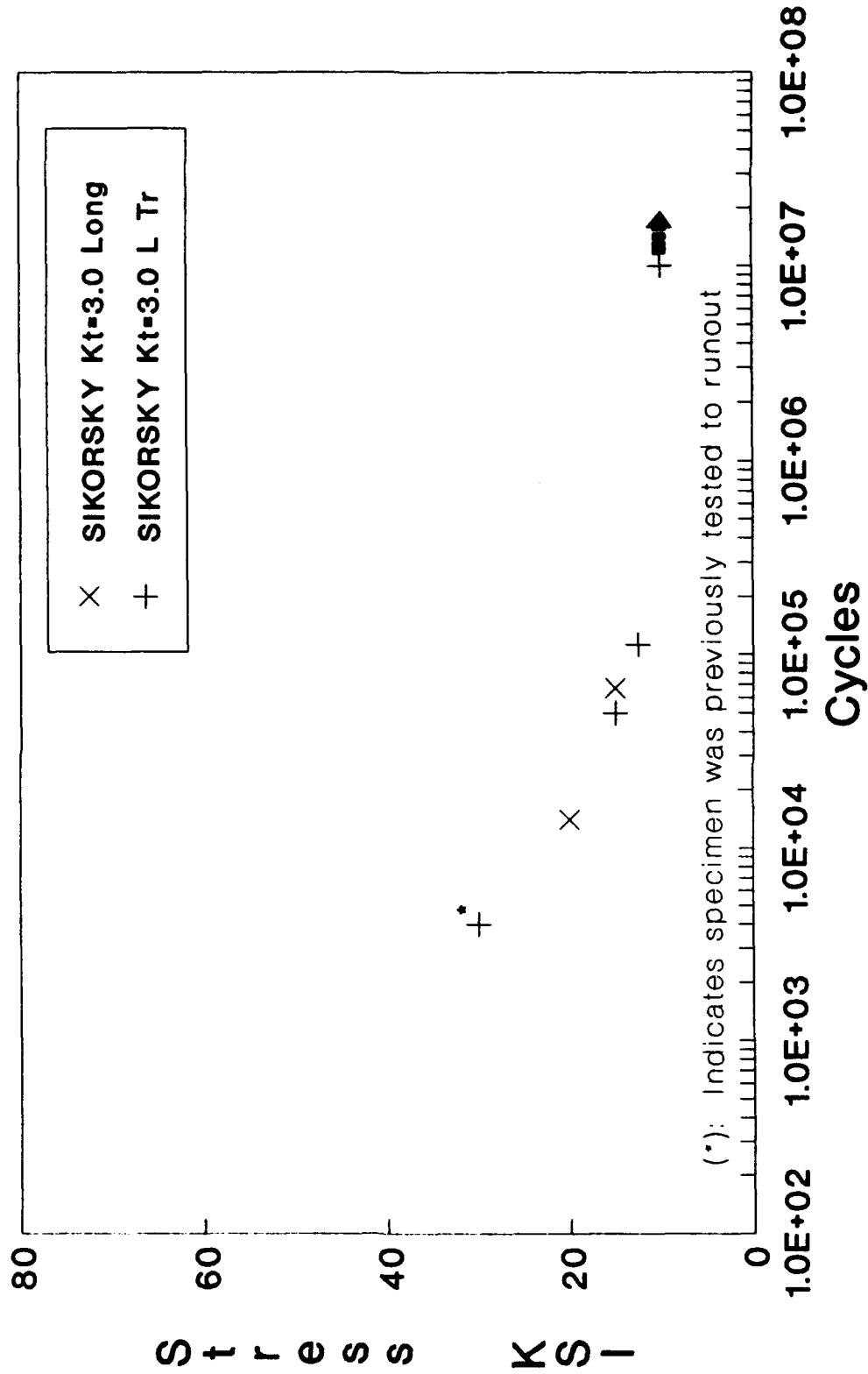


Figure G5 Fatigue Results for IN905XL Forging (R=-1.0, Kt=3.0). Sikorsky.

TABLE G38  
 FATIGUE RESULTS WITH R=-1.0 AND Kt=3.07 FOR  
 IN905XL FORGING

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
<hr/>			
SIKORSKY	LONG	20.0	14,000
		15.0	67,000

(\*): INDICATES A RUNOUT TEST

(#): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 15 KSI

TABLE G39  
FATIGUE RESULTS WITH R=-1.0 AND Kt=3.07 FOR  
IN905XL FORGING

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
<hr/>			
SIKORSKY	L TRANS	30.0	4,000 #
		15.0	50,000
		12.5	112,400
		10.0	10,000,000 *

(\*): INDICATES A RUNOUT TEST

(#): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 10 KSI

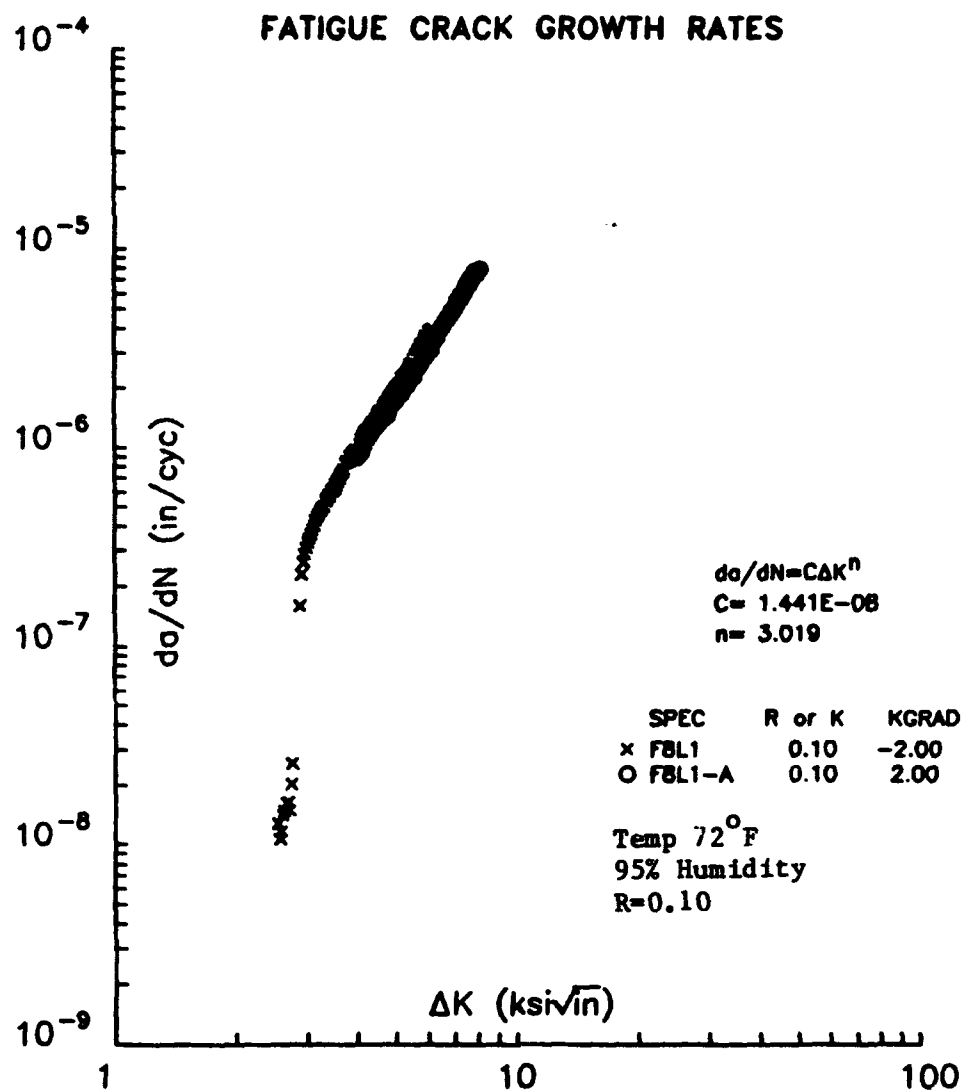


Figure G6 Fatigue Crack Growth Rate Data for IN905XL Forging  
 (L-T Orientation, KGRAD -2.00 and 2.00). Northrop.

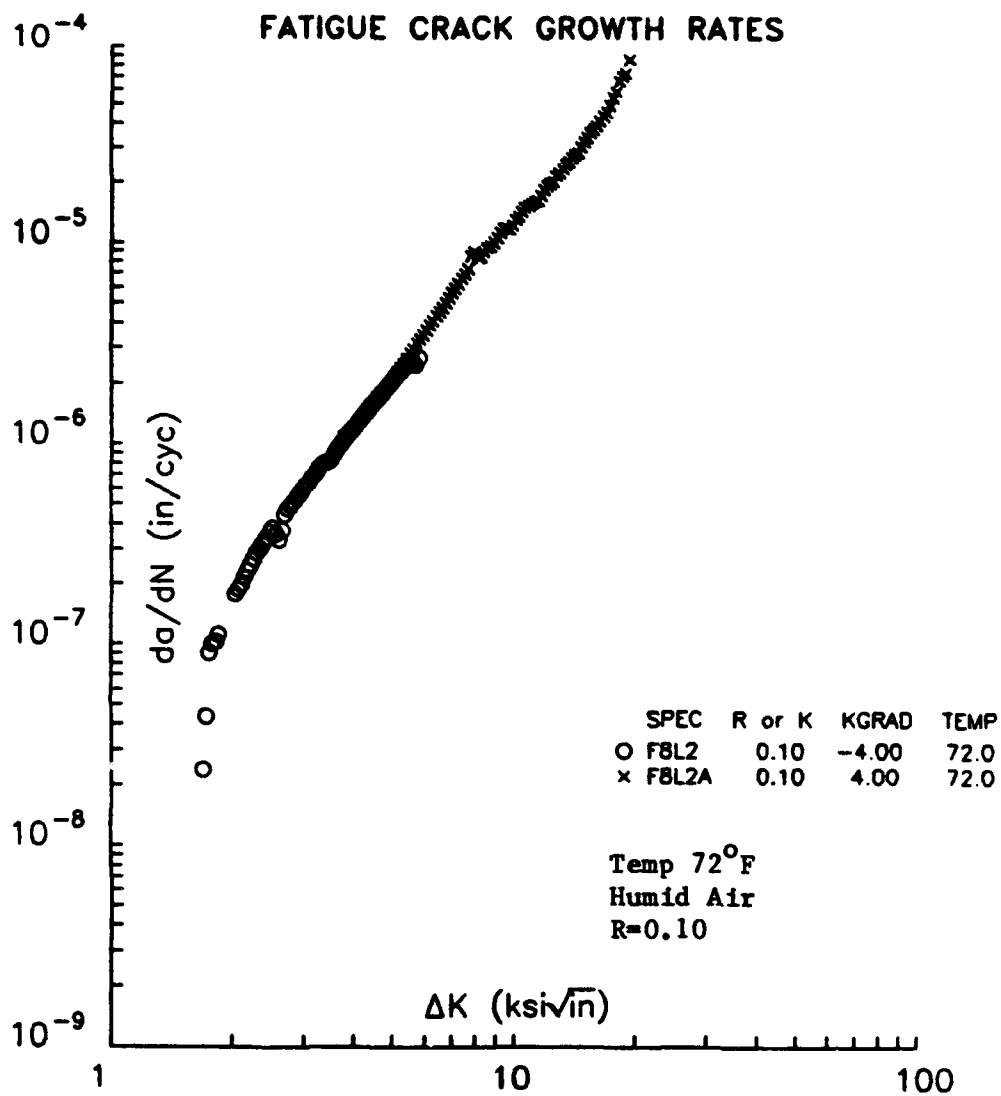


Figure G7 Fatigue Crack Growth Rate Data for IN905XL Forging (L-T Orientation, KGRAD -4.00 and 4.00). Northrop.

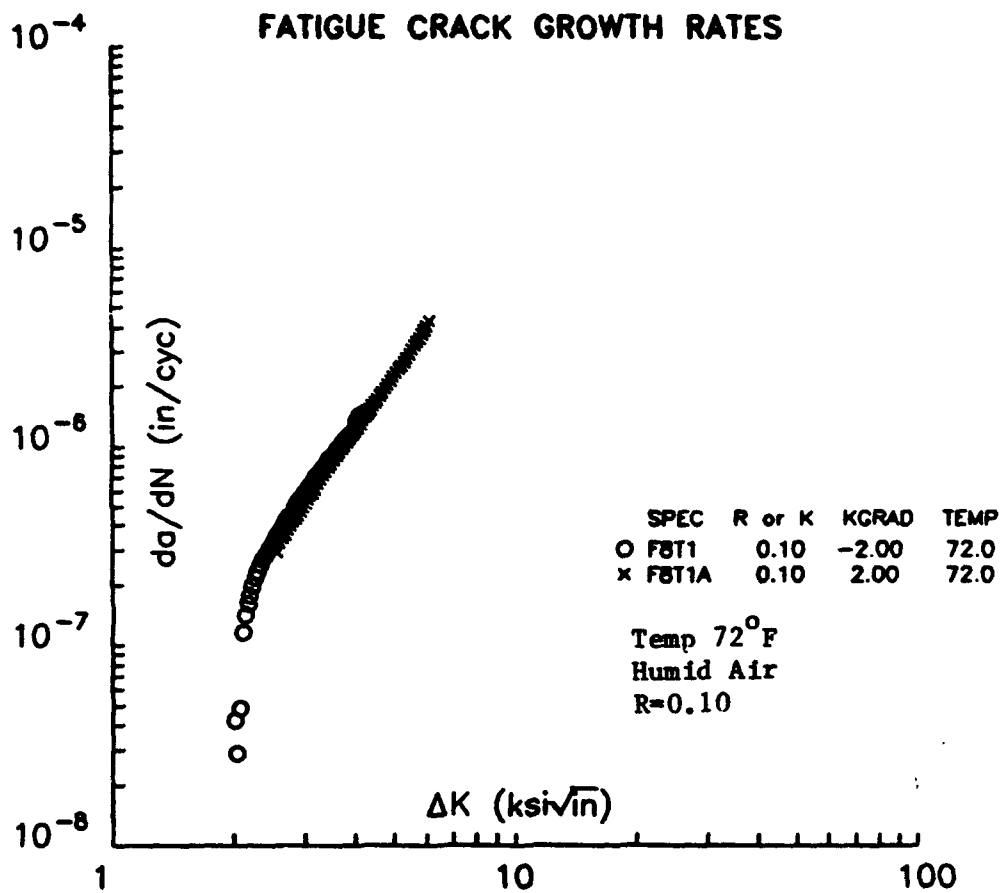


Figure C8 Fatigue Crack Growth Rate Data for IN905YL Forging  
(T-I, Orientation, KGRAD -2.00 and 2.00). Northrop.

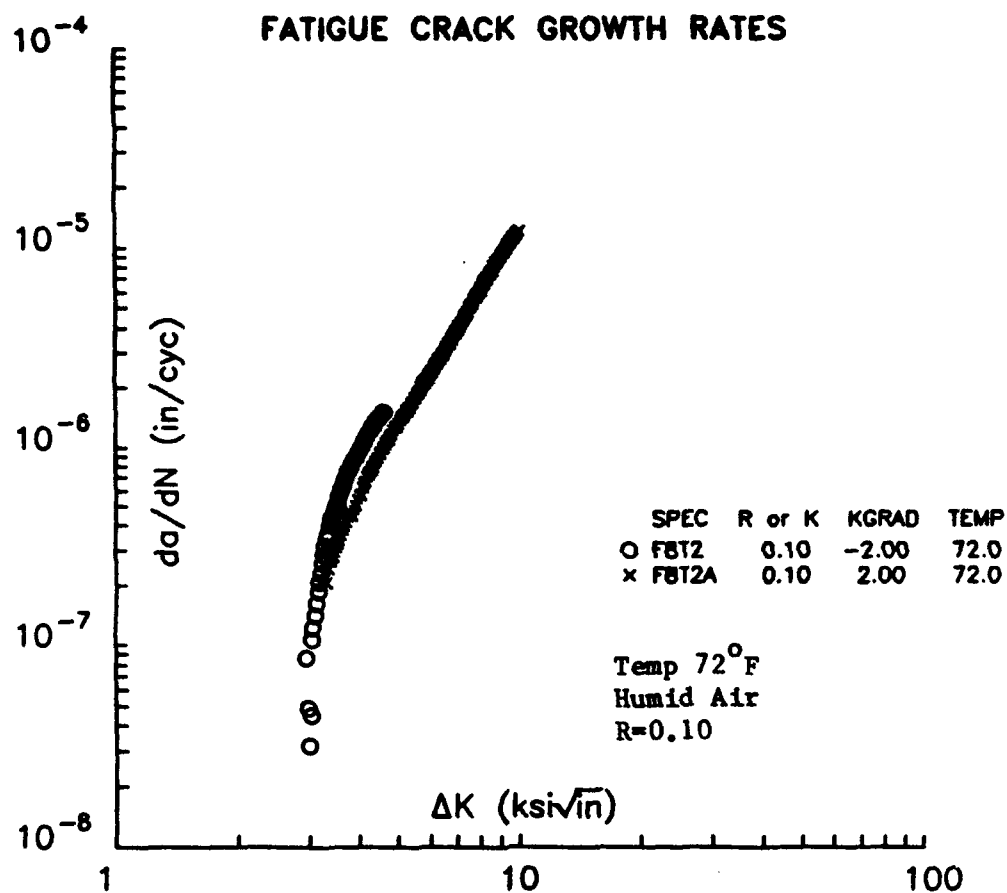


Figure G9 Fatigue Crack Growth Rate Data for IN905XL Forging  
(T-L Orientation, KGRAD -4.00 and 4.00). Northrop.

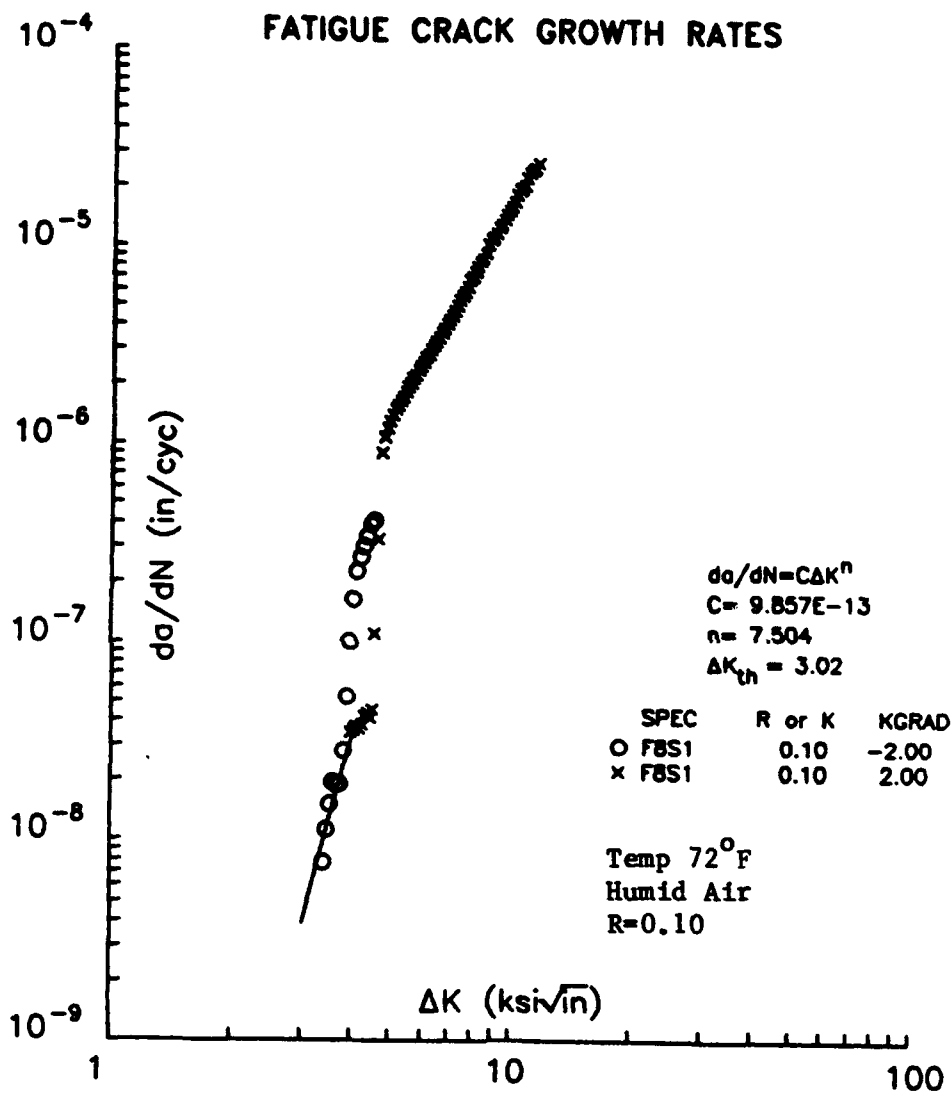


Figure G10 Fatigue Crack Growth Rate Data for IN905VL Forging (S-L Orientation, KGRAD -2.00 and 2.00). Northrop.

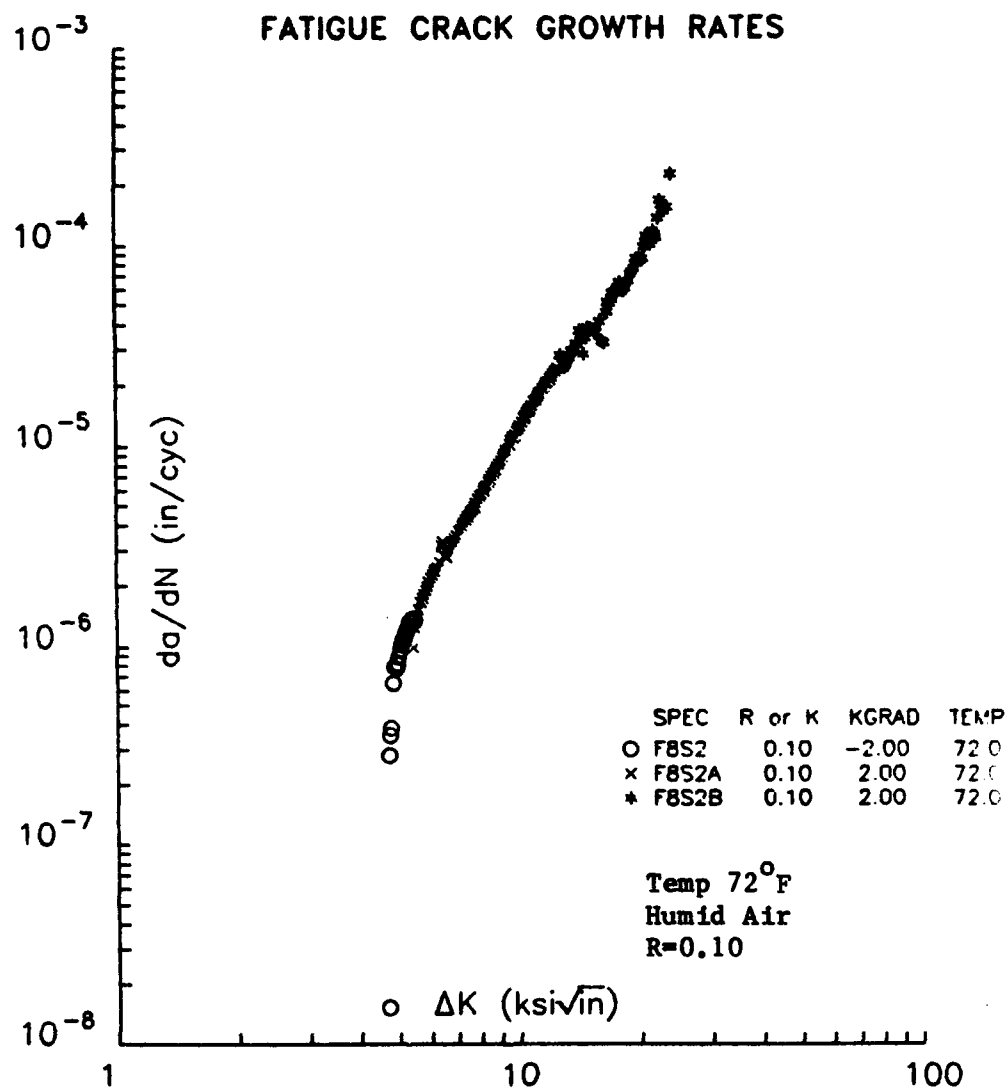


Figure C11 Fatigue Crack Growth Rate Data for IN905XL Forging  
(S-L Orientation, KGRAD -2.00, 2.00 and 2.00). Northrop.

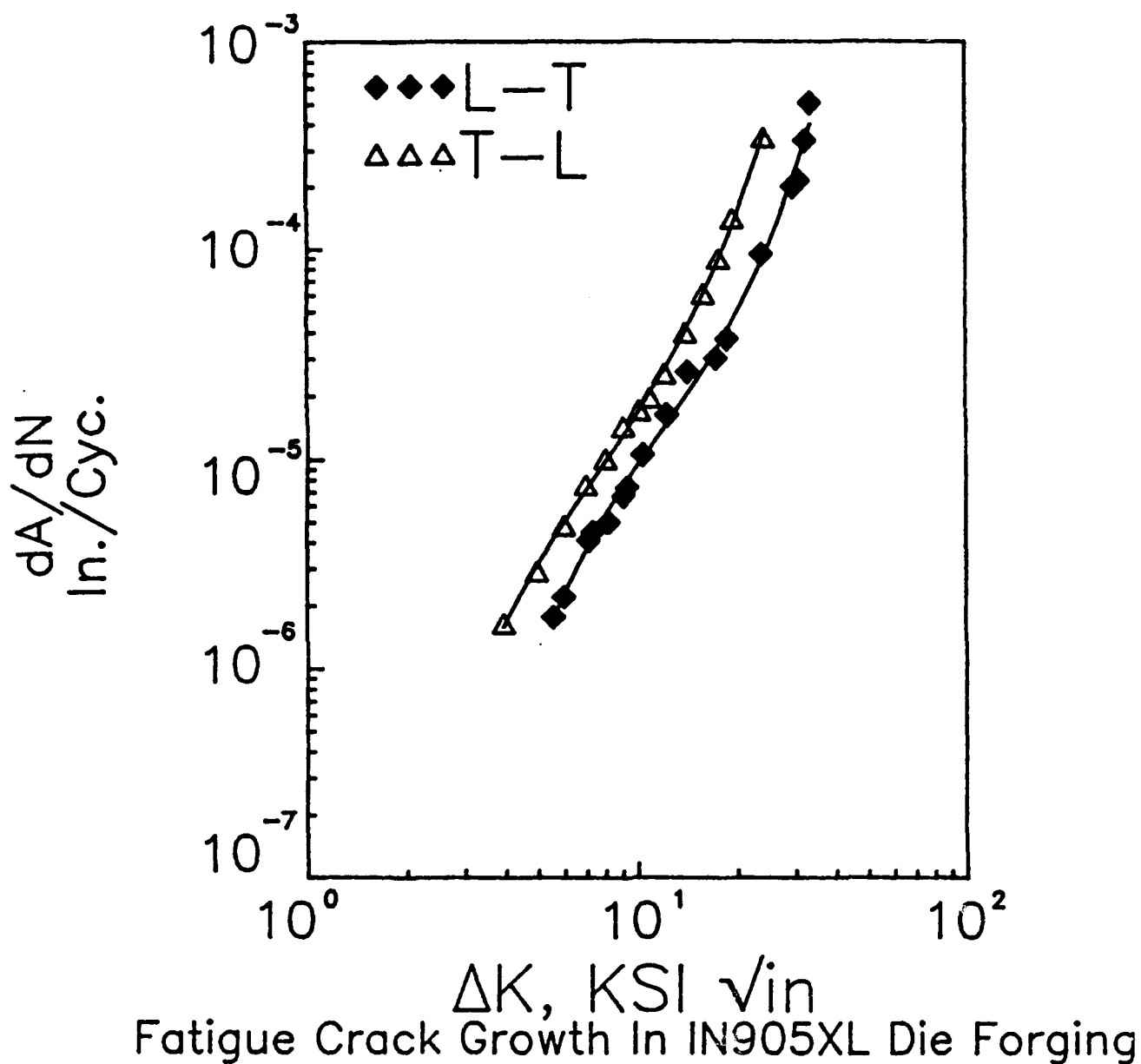


Figure G12 Fatigue Crack Growth Rate Data for Solutiontreated and aged IN905XL Forging (L-T and T-L Orientation,  $R=0.1$ , Lab Air and a third order regression fit to each data set). General Dynamics TX.

MCDONNELL AIRCRAFT COMPANY

WOL 1 & 2 (L-LT)

⊙ DENOTES THAT DATA POINT IS INVALID PER ASTM E47-63, PARAGRAPH 6.6.4.

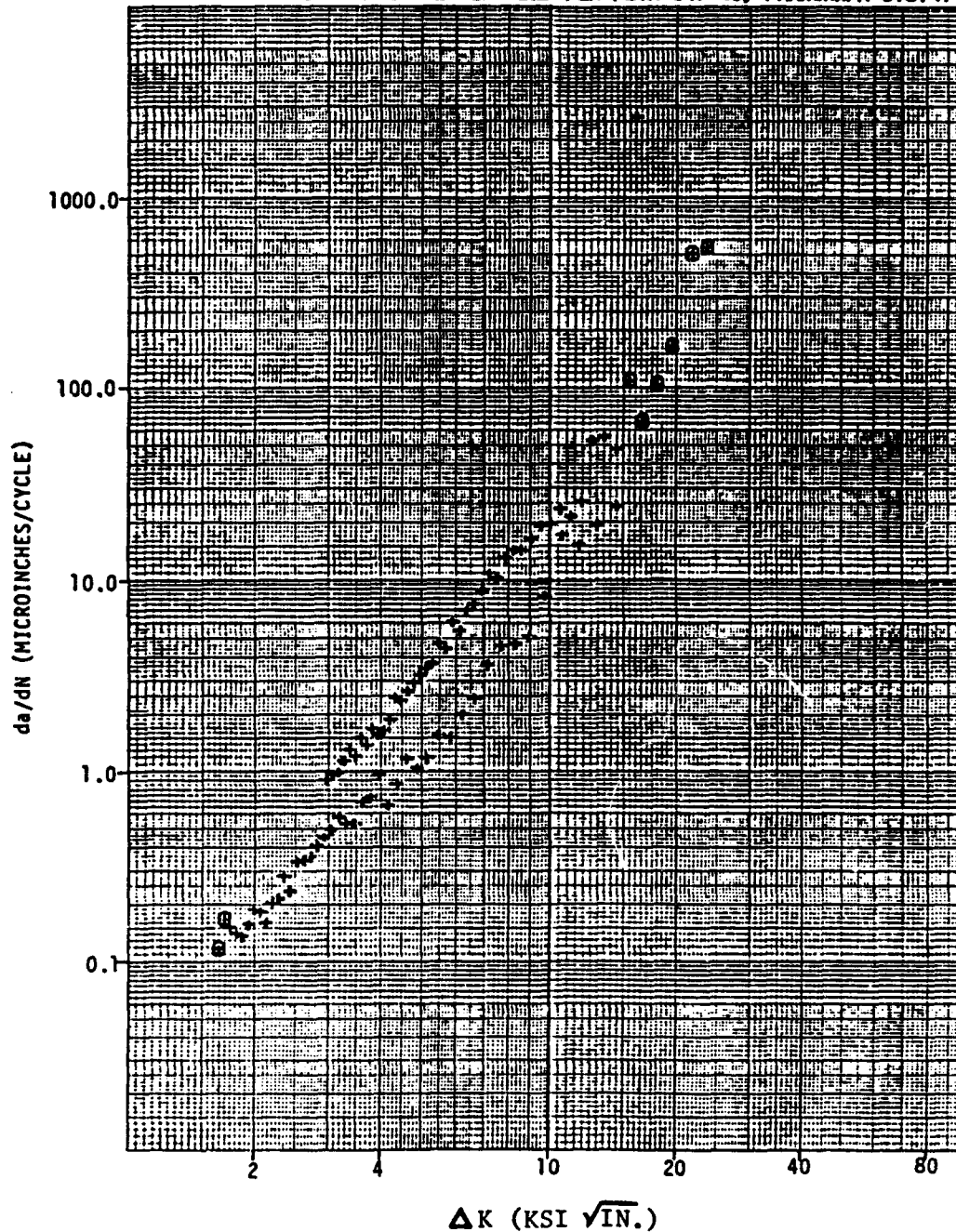


Figure G13 Fatigue Crack Growth Rate Data for IN905XL Forging (WOL Specimen, L-T Orientation,  $R=0.02$ , Lab Air). McDonnell Aircraft Co.

**MCDONNELL AIRCRAFT COMPANY**

WOL 3 & 4 (LT-L)

● DENOTES THAT DATA POINT IS INVALID PER ASTM G47-83, PARAGRAPH 8.6.4.

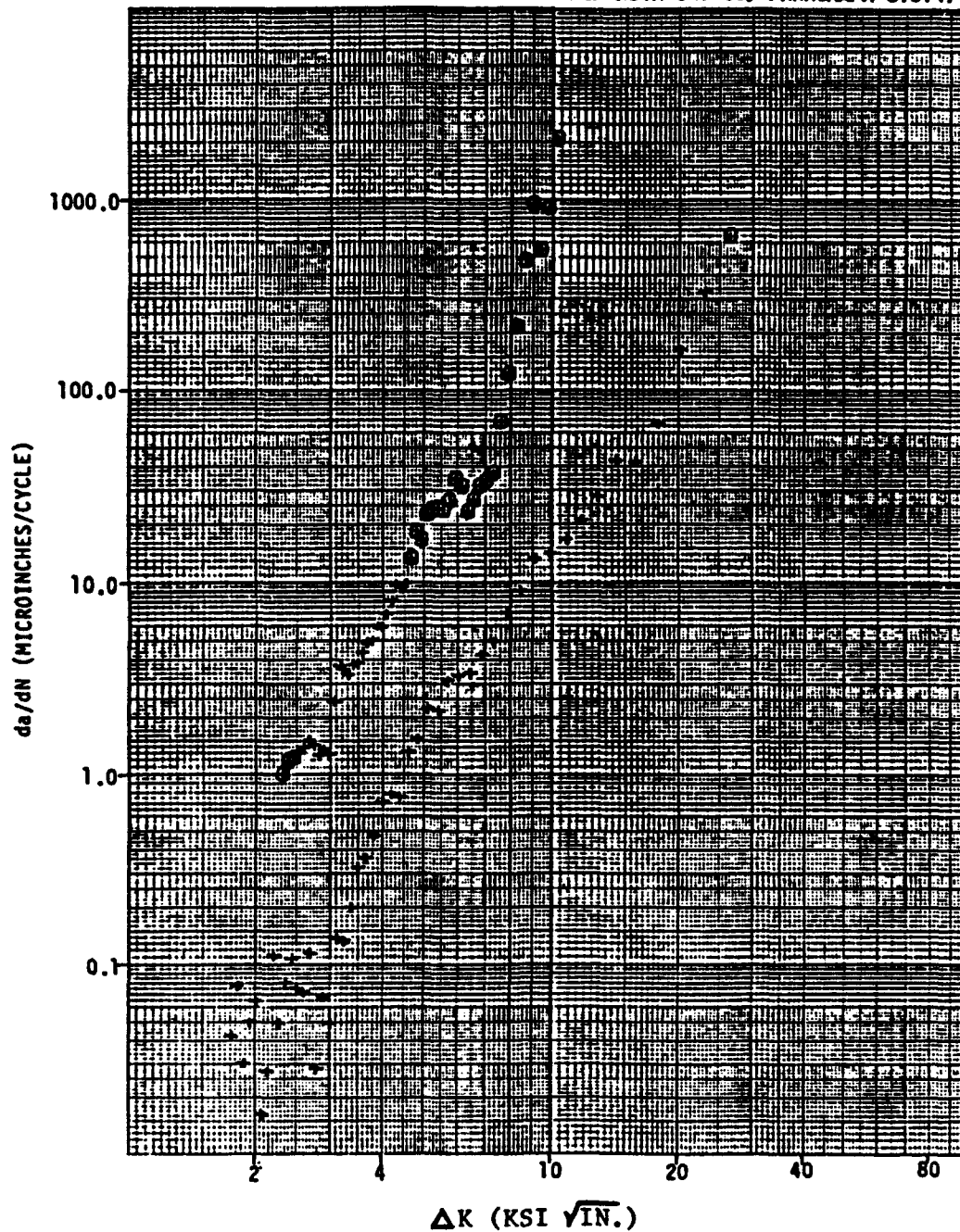


Figure G14 Fatigue Crack Growth Rate Data for IN905XL Forging  
(WOL Specimen, T-L Orientation, R=0.02 and Lab Air).  
McDonnell Aircraft Co.

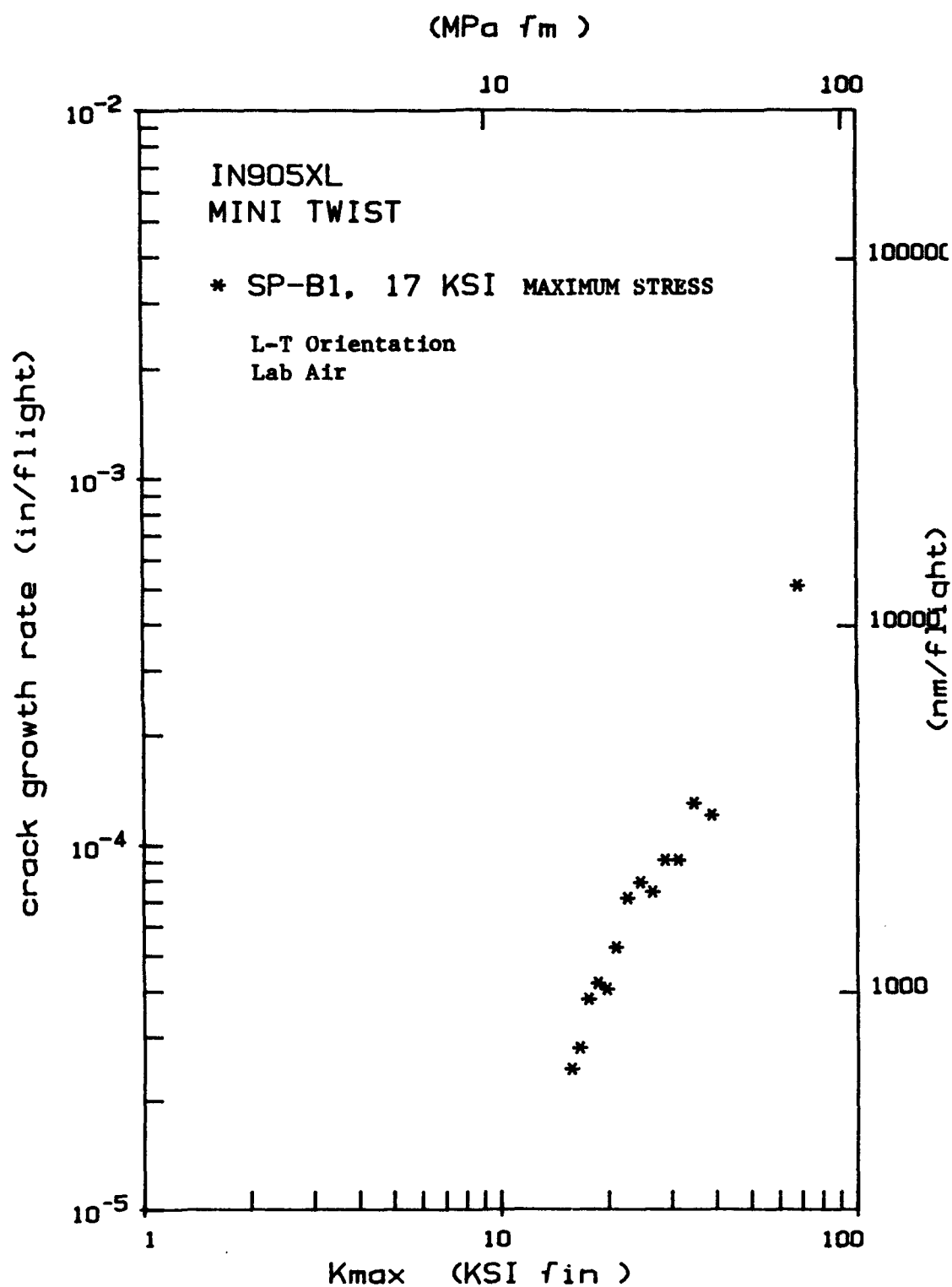


Figure G15

Mini-TWIST Spectrum Fatigue Crack Growth Rate Data.  
Air Force.

## **APPENDIX H**

### **AL905XL PRECISION FORGING**

#### **INTRODUCTION**

The IN905XL and AL905XL are the same alloy but they were produced in different years and production plants. In 1989, Inco Alloys International constructed a production facility to make the AL905XL and other mechanically alloyed aluminum alloys. Production practices through all stages of alloy manufacture were changed to yield greatly improved reproducibility.

The AL905XL forgings were received the second quarter of 1989. All the participants tested the material in the as received condition. Figure H1 shows the geometry of the AL905XL back-up fitting precision forging.

#### **TESTING**

Basic mechanical properties (tension, compression, bearing, etc.) were tested according to ASTM standards, unless otherwise specified.

Constant amplitude fatigue crack growth tests were conducted according to ASTM E647 standard. The growth rate  $a-N$  data that were generated by the participants (Northrop, McDonnell Aircraft Company and the Air Force) were reduced using a seven-point incremental polynomial method. This involves fitting a second-order polynomial (parabola) to sets of seven successive data points. The data are also checked against size requirements per ASTM E647, Section 7.2. Northrop also performed two constant amplitude fatigue crack growth tests using a  $K$ -decreasing method.

Spectrum fatigue crack growth tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

Stress Corrosion tests were performed by Wyman Gordon and the results are shown in tabular form.



**TABLE H1**  
**TENSILE RESULTS FOR**  
**INCOMAP AL905XL DIE FORGING**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	LONG	79.0	70.9		24.0	
			77.3	67.8		16.7	
			76.9	71.7	9.9	22.6	
LTV	RT	LONG	74.7	66.7	12.0		13.4
			74.5	67.5	7.7		13.2
			75.0	67.7	11.6		13.1
MCAIR	RT	LONG	75.0	66.0	11.0	22.1	11.3
			75.5	66.5	11.0	20.0	11.9
			75.0	65.5	11.0	17.8	10.6
WYMAN-GORDON	RT	LONG	75.2	67.8	9.0		
			73.6	62.8	12.0		
			73.2	64.2	11.0		
NASA-LANGLEY	RT	LONG	76.7	67.7	9.0		11.3
			76.1	67.9	9.0		11.3
			77.1	68.7	8.8		11.3
MCDONNELL DOUGLAS HELICOPTER	RT	LONG	73.5	65.7	13.0		
			72.5	64.1	13.0		
			73.3	62.1	12.0		
MARTIN MARIETTA	RT	LONG	75.3	64.3	12.0	18.3	11.6
			75.3	65.0	12.0	23.2	12.0
			72.9	61.2	12.0	24.1	11.6
NORTHROP	RT	LONG	76.1	66.8	10.2	27.8	12.1
			76.0	66.9	7.8	18.9	11.8
			76.1	67.1	8.6	18.3	11.7
AVERAGE			75.2	66.4	10.6	21.1	11.9
STANDARD DEVIATION			1.6	2.5	1.6	3.3	0.8

**TABLE H2**  
**TENSILE RESULTS FOR**  
**INCOMAP AL905XL DIE FORGING**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	L TRANS	72.0	60.4	8.7	20.8	
			72.5	62.4	8.7	16.6	
			71.1	58.1	8.3	16.7	
LTV	RT	L TRANS	71.8	61.2	8.0		13.1
			72.2	61.3	8.8		12.8
			71.4	58.9	8.4		12.9
MCAIR	RT	L TRANS	72.5	60.0	9.0	13.6	11.2
			72.5	60.0	9.0	16.5	11.2
			73.0	60.0	7.0	13.8	10.5
WYMAN-GORDON	RT	L TRANS	72.0	60.8	8.0		
			72.2	57.2	8.0		
			72.3	60.1	8.0		
NASA-LANGLEY	RT	L TRANS	73.5	60.5	7.5		11.2
			73.5	60.5	7.1		11.2
			73.1	59.2	8.8		11.2
MCDONNELL DOUGLAS HELICOPTER	RT	L TRANS	68.0	57.0	7.0		
			67.3	53.7	7.0		
			71.3	62.6	12.0		
MARTIN MARIETTA	RT	L TRANS	72.4	58.7	11.0	17.6	
			71.8	60.2	11.0	13.9	
			71.7	56.8	12.0	16.1	
NORTHROP	RT	L TRANS	72.9	58.5	8.6	18.3	11.5
			73.9	60.4	6.2	14.4	11.2
			74.4	61.3	9.4	14.4	11.7
AVERAGE			72.1	59.6	8.6	16.1	11.6
STANDARD DEVIATION			1.6	2.0	1.5	2.2	0.8

**TABLE H3**  
**TENSILE RESULTS FOR**  
**INCOMAP AL905XL DIE FORGING**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	S TRANS	72.6	58.6	6.4	12.3	
			72.5	59.4	5.3	13.8	
			72.4	59.5	3.9	7.8	
LTV	RT	S TRANS	69.1	56.4	3.1		13.3
			71.2	58.4	5.3		13.9
			69.4	56.0	3.1		14.3
MCAIR	RT	S TRANS	70.5	61.5	5.0	7.9	13.4
			71.5	58.5	7.0	12.4	10.8
			71.5	59.0	8.0	14.8	10.9
WYMAN-GORDON	RT	S TRANS	69.6	54.4	6.0		
			70.0	56.0	8.0		
			70.6	56.1	7.0		
NASA-LANGLEY	RT	S TRANS	70.4	56.3	4.9		11.2
			70.6	55.7	4.8		11.2
			70.8	55.3	4.8		11.1
MCDONNELL DOUGLAS HELICOPTER	RT	S TRANS	67.7	54.5	11.0		
			68.0	54.0	10.0		
			68.7	55.6	10.0		
MARTIN MARIETTA	RT	S TRANS	68.3	57.1	4.0	7.0	11.7
			70.2	54.7	5.0	5.5	11.5
			68.4	54.9	5.0	4.0	11.5
NORTHROP	RT	S TRANS	72.4	59.4	7.8	17.8	11.2
			71.1	57.6	7.8	9.7	11.5
			71.5	57.9	7.8	16.5	11.3
AVERAGE			70.4	57.0	6.3	10.8	11.9
STANDARD DEVIATION			1.5	2.0	2.2	4.5	1.2

**TABLE H4**  
**COMPRESSION RESULTS FOR**  
**INCOMAP AL905XL DIE FORGING**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
LTV	RT	LONG	72.5	11.8
			73.9	11.7
			73.3	12.2
MCAIR	RT	LONG	64.0	9.9
			66.0	10.3
			56.5	9.4
WYMAN-GORDON	RT	LONG	64.4	
			70.0	
			70.6	
NASA-LANGLEY	RT	LONG	70.5	11.5
			70.3	11.5
MARTIN MARIETTA	RT	LONG	70.4	
			72.0	
			70.4	
NORTHROP	RT	LONG	70.9	11.8
			70.4	11.7
			67.1	11.8
AVERAGE			69.0	11.2
STANDARD DEVIATION			4.3	0.9

**TABLE H5**  
**COMPRESSION RESULTS FOR**  
**INCOMAP AL905XL DIE FORGING**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
NASA-LANGLEY	RT	L TRANS	56.4	11.5
			55.3	11.4
			55.9	11.5
		AVERAGE	55.9	11.5
		STANDARD DEVIATION	0.6	0.1

**TABLE H6**  
**COMPRESSION RESULTS FOR**  
**INCOMAP AL905XL DIE FORGING**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
LTV	RT	S TRANS	58.5	11.8
			58.8	11.6
			60.5	12.2
MCAIR	RT	S TRANS	54.0	10.4
			53.5	9.6
			64.0	10.4
WYMAN-GORDON	RT	S TRANS	60.6	
			63.1	
			61.5	
MARTIN MARIETTA	RT	S TRANS	57.1	
			58.2	
			57.1	
NORTHROP	RT	S TRANS	56.9	11.7
			57.8	11.8
			58.1	11.8
		AVERAGE	58.6	11.3
		STANDARD DEVIATION	2.9	0.9

**TABLE H7**  
**AMSLER DOUBLE SHEAR RESULTS FOR**  
**INCOMAP AL905XL DIE FORGING**

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
LTV	L - S	32.8
		33.1
		36.5
NASA-LANGLEY	L - S	42.3
		41.1
		41.6
MCDONNELL DOUGLAS HELICOPTER	L - S	41.4
		41.5
		41.7
NORTHROP	L - S	39.1
		41.2
		41.9
AVERAGE		39.5

**TABLE H8**  
**PIN SHEAR RESULTS FOR**  
**INCOMAP AL905XL DIE FORGING**

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
MCAIR	L - S	42.2
		40.6
		42.0
WYMAN-GORDON	L - S	40.4
		50.0
		40.2
AVERAGE		42.6
STANDARD DEVIATION		3.7

TABLE H9  
BEARING RESULTS FOR  
INCOMAP AL905XL DIE FORGING

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR. (KSI)	YIELD	STR. (KSI)
LTV	LONG	1.5		100.7		88.7
				96.0		91.4
MCAIR	LONG	1.5		101.4		
				100.2		
WYMAN-GORDON	LONG	1.5		103.1		
				99.2		
NORTHROP	LONG	1.5		101.6		91.3
				98.5		89.1
AVERAGE				100.1		90.1
STANDARD DEVIATION				2.2		1.4

TABLE H10  
BEARING RESULTS FOR  
INCOMAP AL905XL DIE FORGING

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
LTV	LONG	2.0				
MCAIR	LONG	2.0				
WYMAN-GORDON	LONG	2.0				
NORTHROP	LONG	2.0				
AVERAGE						
STANDARD DEVIATION						

**TABLE H11**  
**FRACTURE TOUGHNESS RESULTS FOR**  
**INCOMAP AL905XL DIE FORGING**

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
AIR FORCE	L-T	27.1		VALID
		23.6		VALID
LTV	L-T	28.9		VALID
		27.7		VALID
MCAIR	L-T		27.1	INVALID (1)
		29.9		VALID
WYMAN-GORDON	L-T	29.5		VALID
		28.9		VALID
MCDONNELL	L-T		31.1	INVALID (2)
DOUGLAS			29.9	INVALID (2)
HELICOPTER				
MARTIN	L-T	31.2		VALID
MARIETTA		30.8		VALID
NORTHROP	L-T	29.1		VALID
			29.9	INVALID (2)
	AVERAGE	28.7	29.5	
	STANDARD DEVIATION	2.2	1.7	

(1): DIFF. BETWEEN SURFACE CRACK LENGTHS > 10% OF AVERAGE CRACK LENGTH

(2): Pmax/Pq EXCEEDED 1.10

TABLE H12  
FRACTURE TOUGHNESS RESULTS FOR  
INCOMAP AL905XL DIE FORGING

COMPANY	ORIENTATION	KIC	Kq	COMMENT
		(KSI in^0.5)	(KSI in^0.5)	
AIR FORCE	T-L	22.3		VALID
		21.3		VALID
LTV	T-L	19.0		VALID
		19.1		VALID
MCAIR	T-L	25.7		VALID
		24.0		VALID
WYMAN-GORDON	T-L	22.2		VALID
		20.4		VALID
MCDONNELL	T-L		28.2	INVALID(1)
DOUGLAS			29.0	INVALID(1)
HELICOPTER				
MARTIN	T-L	23.1		VALID
MARIETTA				
NORTHROP	T-L	24.1		VALID
		25.4		VALID
AVERAGE		22.4	28.6	
STANDARD DEVIATION		2.3	0.6	

(1): P<sub>max</sub>/P<sub>q</sub> EXCEEDED 1.10

TABLE H13  
FRACTURE TOUGHNESS RESULTS FOR  
INCOMAP AL905XL DIE FORGING

COMPANY	ORIENTATION	K <sub>IC</sub> (KSI in <sup>0.5</sup> )	K <sub>q</sub> (KSI in <sup>0.5</sup> )	COMMENT
AIR FORCE	S-L	21.2		VALID
LTV	S-L	20.5 20.6		VALID VALID
MCAIR	S-L		24.9	INVALID(1)
WYMAN-GORDON	S-L	21.8 20.9		VALID VALID
MARTIN MARIETTA	S-L	22.9	23.6	VALID INVALID(2)
AVERAGE		21.3	24.3	
STANDARD DEVIATION		0.9	0.9	

(1): DIFF. BETWEEN SURFACE CRACK LENGTHS > 10% OF AVERAGE CRACK LENGTH  
(2): PRECRACK LENGTH TOO LONG,  $a/W=0.6$

**TABLE H14**  
**FRACTURE TOUGHNESS RESULTS FOR**  
**INCOMAP AL905XL DIE FORGING**

COMPANY	ORIENTATION	KIC	Kq	COMMENT
		(KSI in^0.5)	(KSI in^0.5)	
-----				
AIR FORCE	S-T	26.1		VALID
		22.3		VALID
LTV	S-T		21.1	INVALID(1)
		24.6		VALID
MCAIR	S-T		27.2	INVALID(2)
			25.2	INVALID(2)
WYMAN-GORDON	S-T	22.6		VALID
		22.9		VALID
MCDONNELL DOUGLAS HELICOPTER	S-T		29.5	INVALID(3)
		26.2		VALID
MARTIN MARIETTA	S-T	24.2		VALID
		24.2		VALID
NORTHROP	S-T	26.2		VALID
		24.1		VALID
	AVERAGE	24.3	25.8	
	STANDARD DEVIATION	1.5	3.6	

(1): CRACK SYMMETRY OUTSIDE LIMITS

(2): DIFF. BETWEEN SURFACE CRACK LENGTHS > 10% OF AVERAGE CRACK LENGTH

(3):  $W, B > 2.5(Kq/Y_S)^{**2}$

# INCOMAP AL905XL Forging

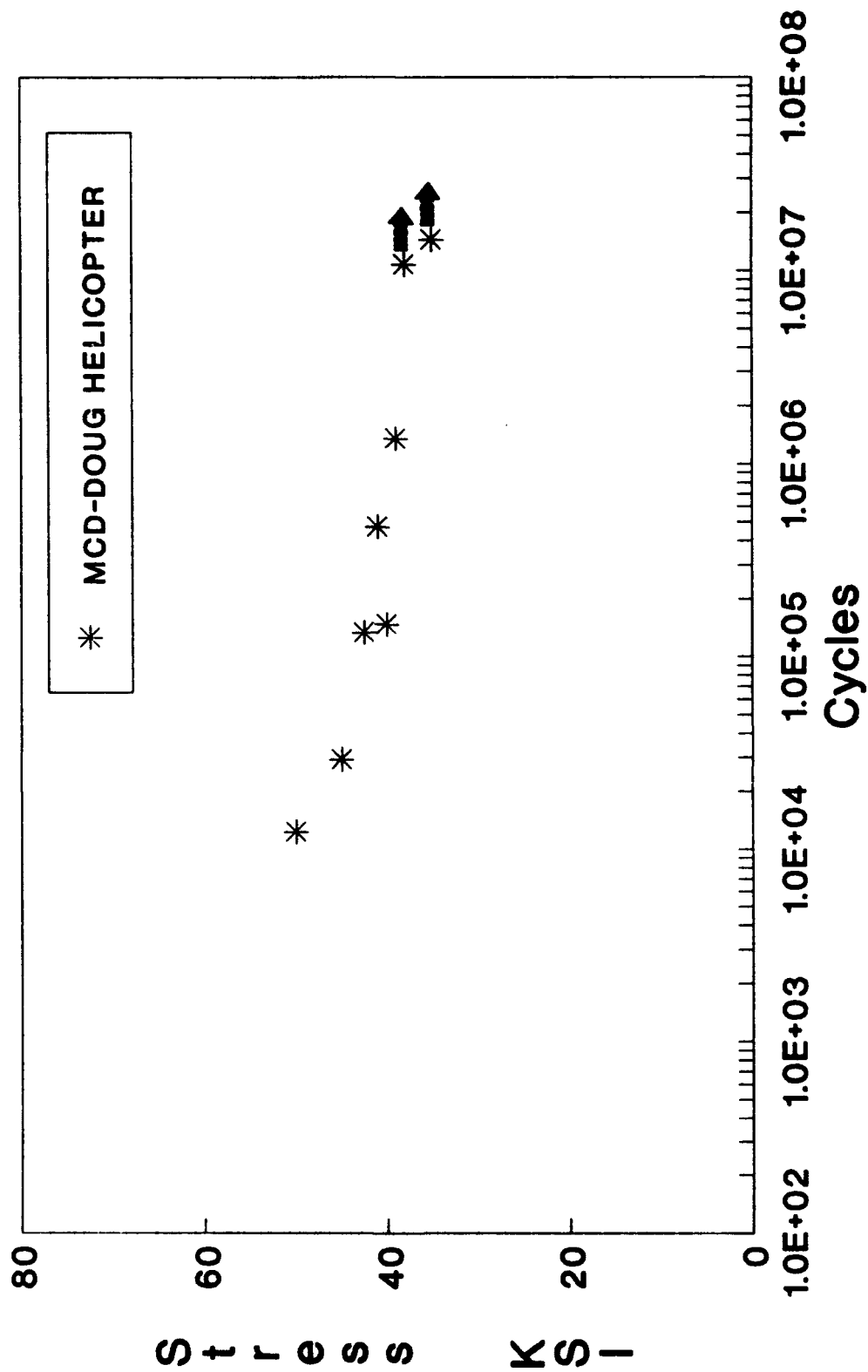


Figure H2 Fatigue Results for AL905XL Forging (Longitudinal Orientation,  $R=0.1$ ,  $K_t=1.0$ ). McDonnell Douglas Helicopter.

**TABLE H15**  
**FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR**  
**INCOMAP AL905XL DIE FORGING**

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
<hr/>			
MCDONNELL	LONG	50.0	12,300
DOUGLAS		45.0	29,200
HELICOPTER		42.5	133,200
		41.0	467,400
		40.0	146,500
		39.0	1,346,200
		38.0	10,685,100 *
		35.0	14,455,400 *

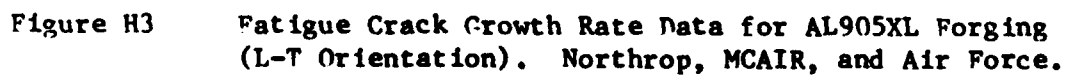
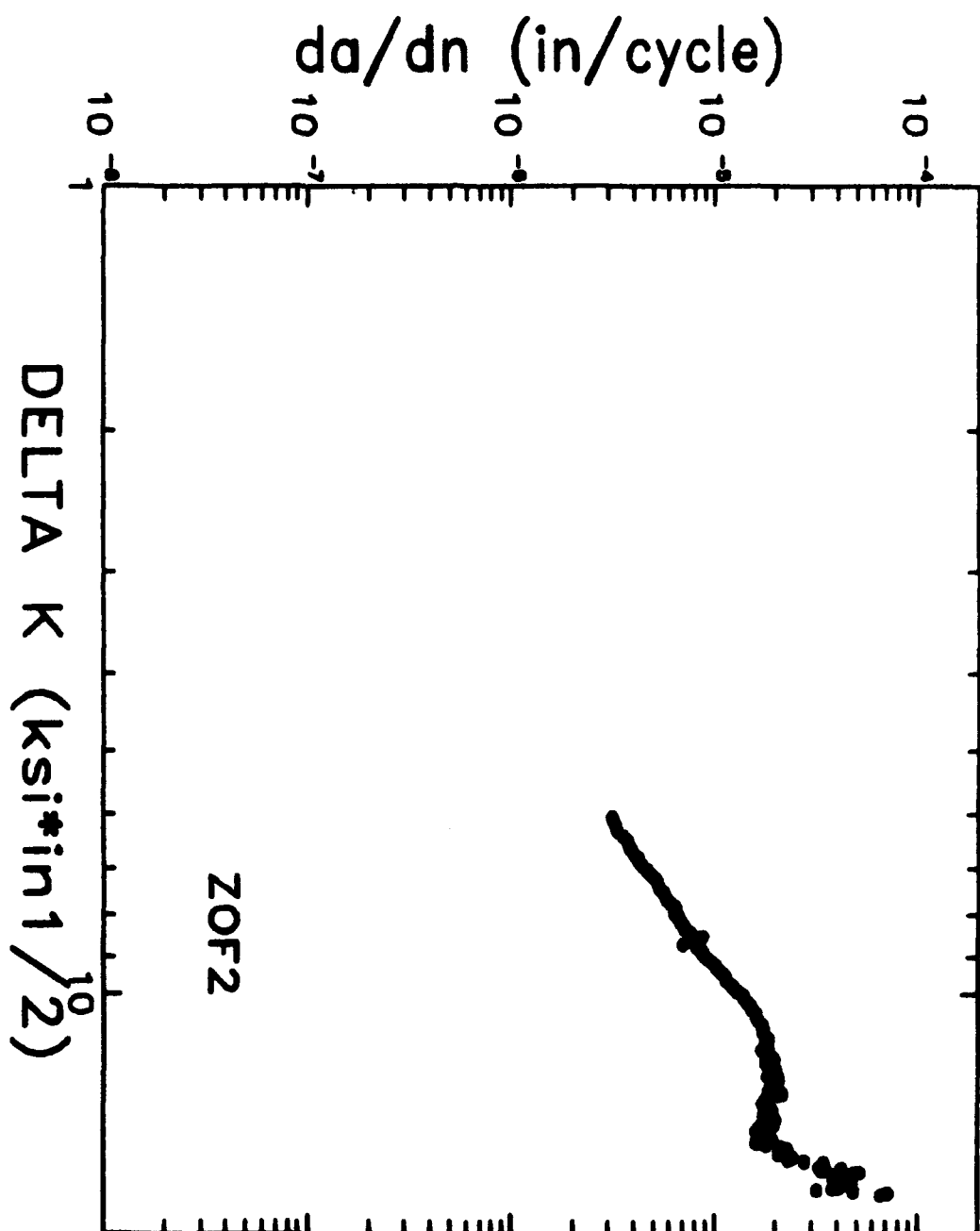
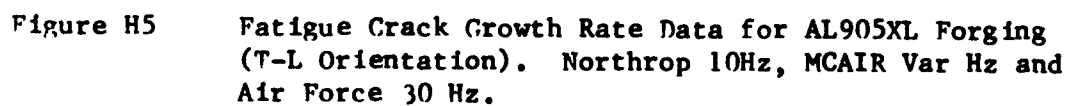


Figure H4  
 Fatigue Crack Growth Rate Data for AL905XL Forging (K-decreasing method,  
 L-T Orientation, R=0.1, Lab Air, Room Temperature). Northrop.





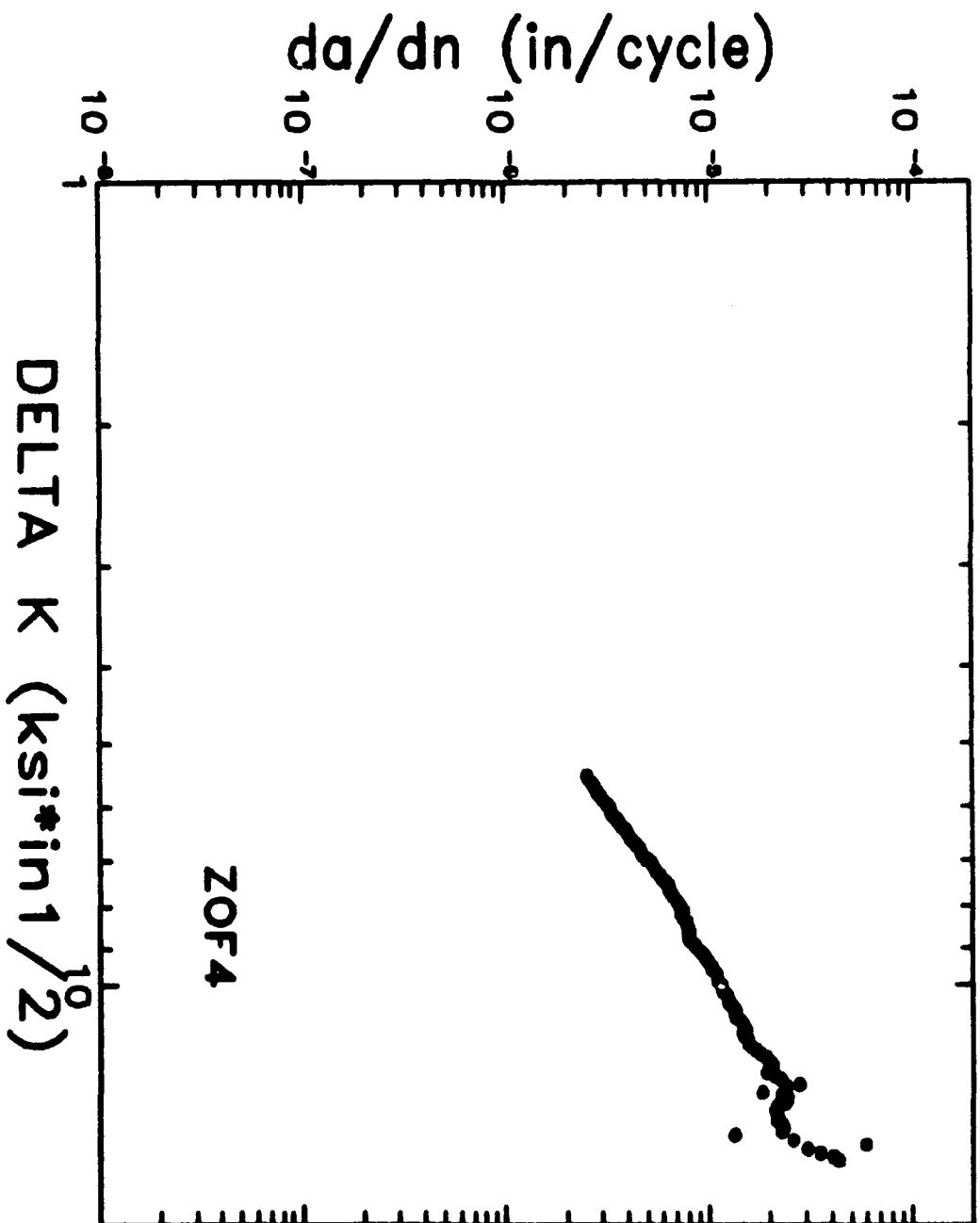


Figure H6  
 Fatigue Crack Growth Rate Data for Al905XL Forging (K-decreasing method, T-L Orientation,  
 R=0.1 Lab Air, Room Temperature). Northrop.

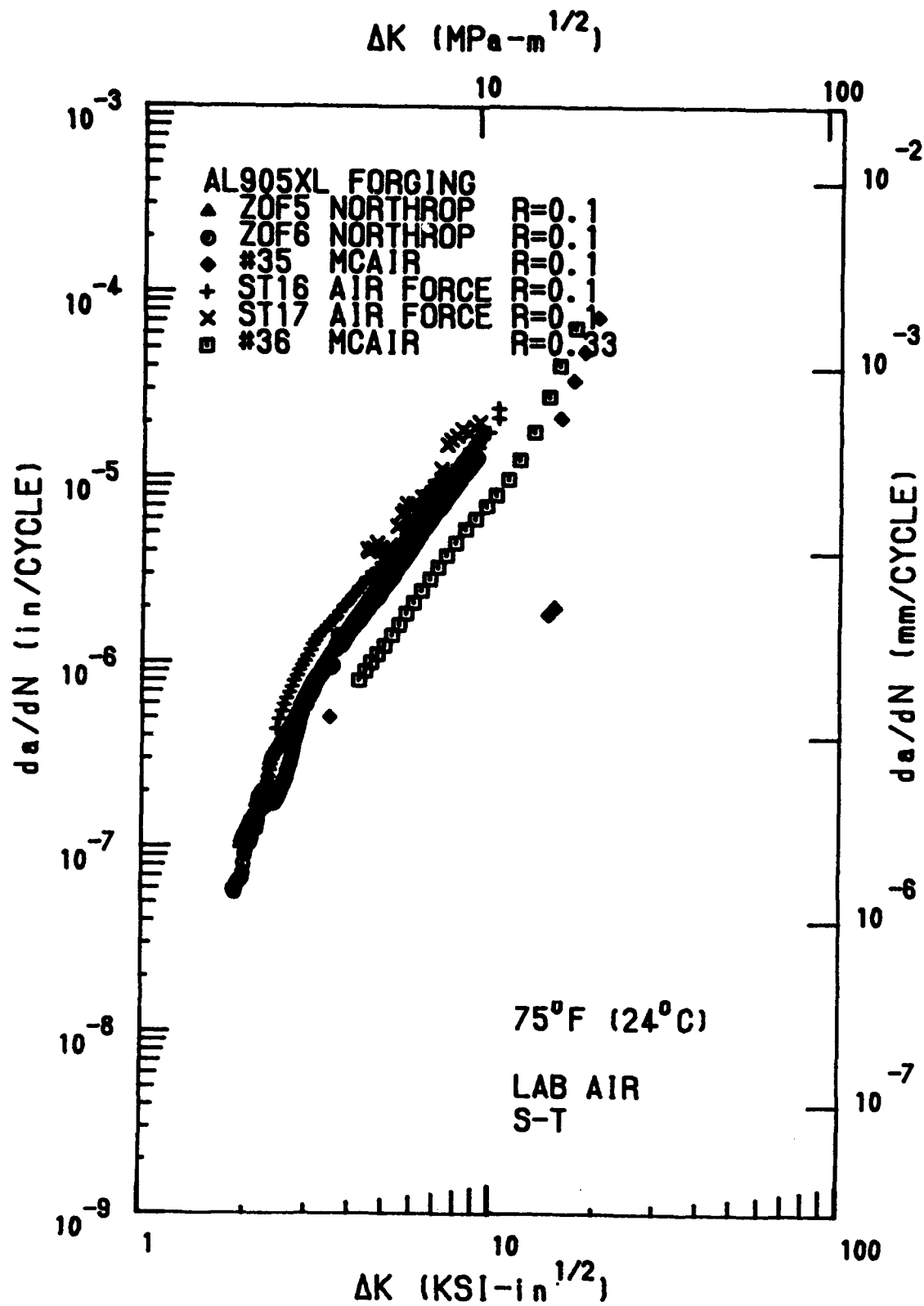


Figure H7 Fatigue Crack Growth Rate Data for AL905XL Forging (S-T Orientation). Northrop 10 Hz, MCAIR Var Hz and Air Force #ST16 25Hz, #ST17 30Hz.

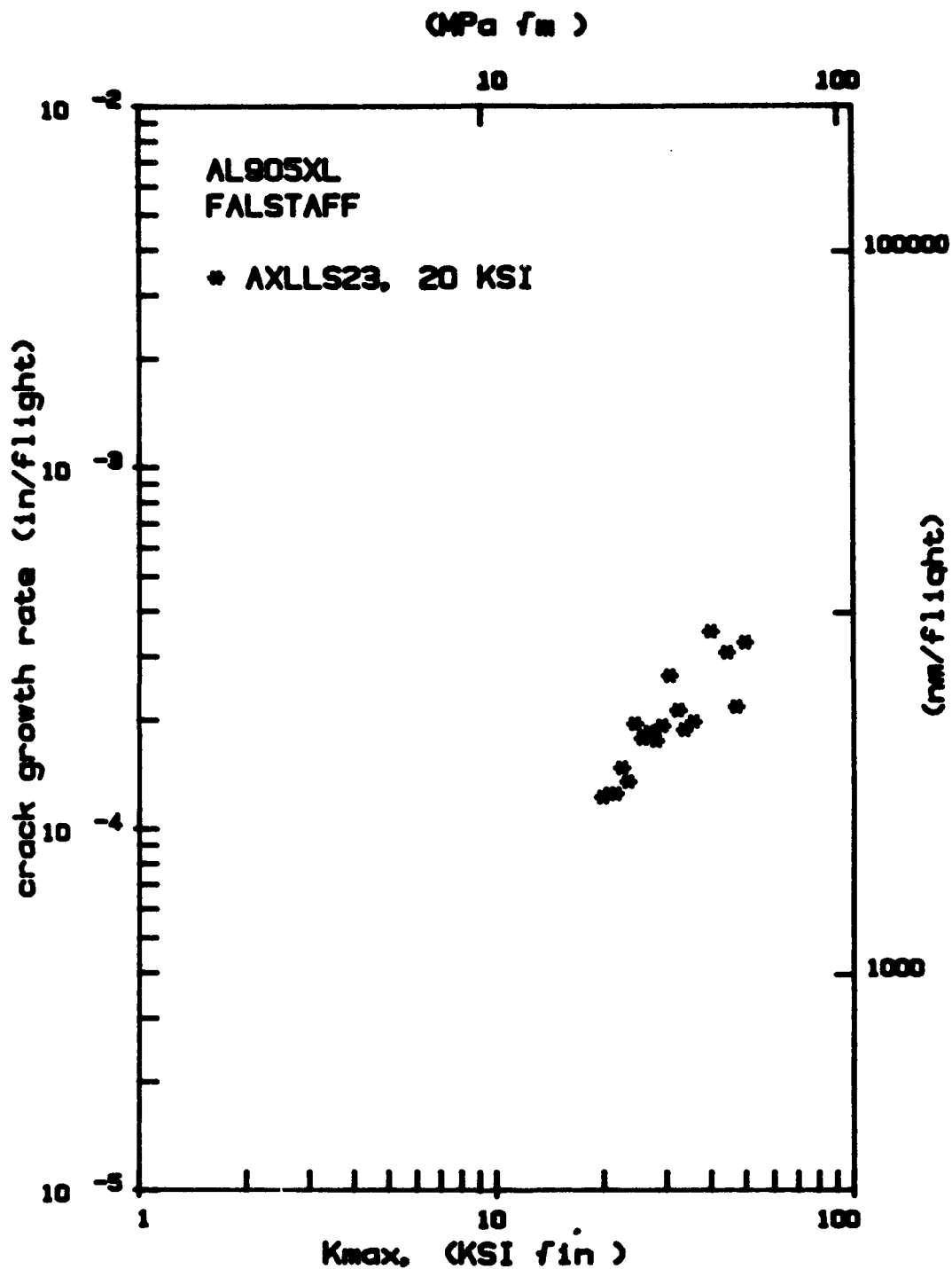


Figure H8 FALSTAFF Spectrum Fatigue Crack Growth Rate Data for AL905XL Forging (L-S Orientation, Maximum Stress = 20 KSI, Lab Air and Room Temperature). Air Force.

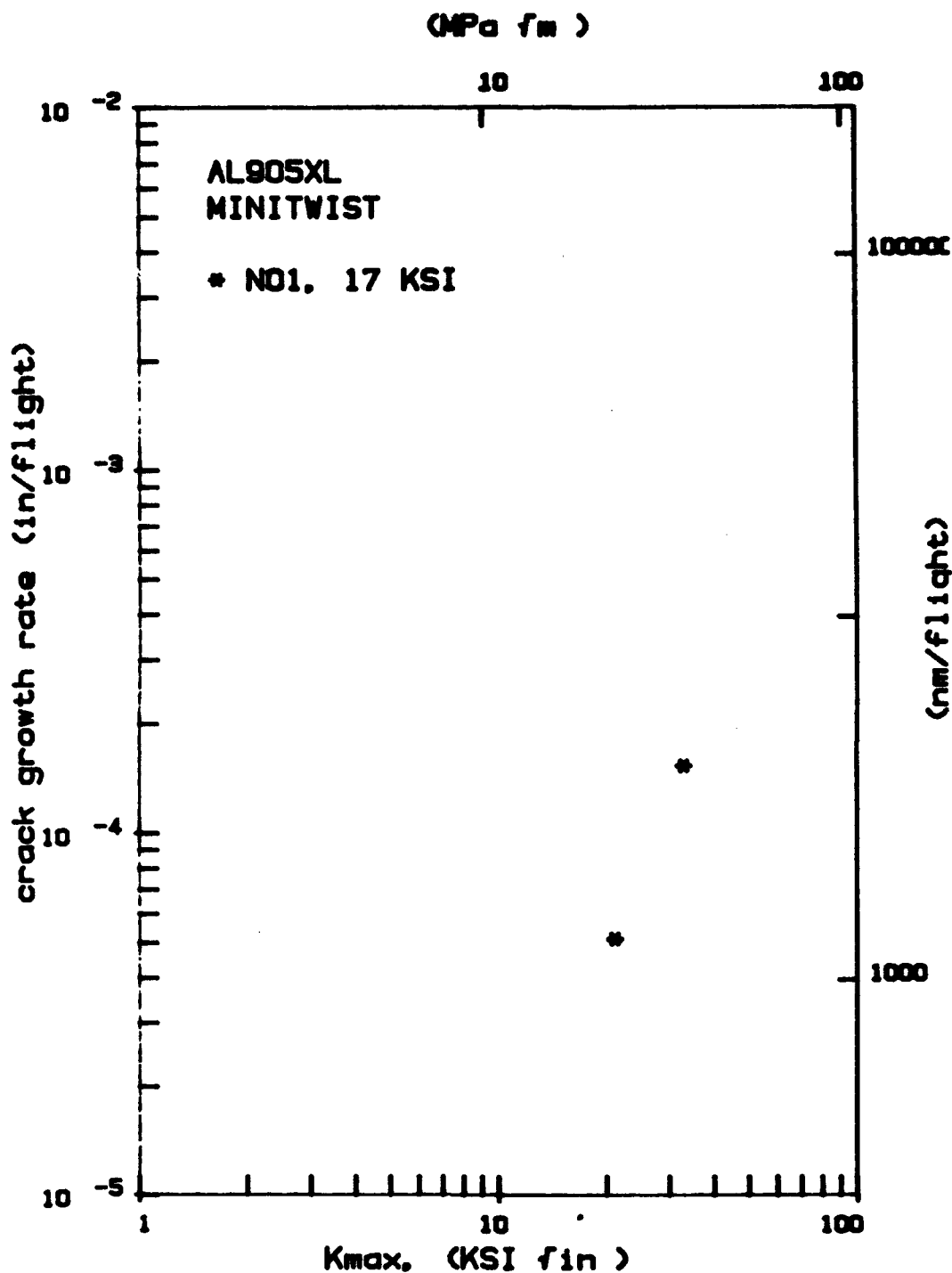


Figure H9 Mini-TWIST Spectrum Fatigue Crack Growth Rate Data for AL905XL Forging (L-S Orientation, Maximum Stress = 16.9 KSI, Lab Air and Room Temperature). Air Force.

**TABLE H16**  
**STRESS CORROSION PROPERTIES**  
**FOR AL905XL FORGING**  
**WYMAN GORDON**

**ASTM G47**

**Specimen Size: .125" dia. x 1.80" long**

**Tested at Dirats Laboratories**

<u>S/N</u>	<u>Orientation</u>	<u>Location</u>	<u>Applied Load (ksi)</u>	<u>No. of Days to Failure</u> <sup>**</sup>
31	S	rail	30	Passed
32	S	rail	30	Passed
33	S	rib	30	Passed
34	S	rail	40	Passed
35	S	rail	40	Passed
36	S	rib	40	Passed
39***	S	rail	50	Passed
40	S	rail	55	Passed

**\*\* Minimum 30 days by alternate immersion in 3.5% NaCl.**

**\*\*\* Specimens actually ran 50 days and then was terminated.**

## **APPENDIX I**

### **WELDALITE 049<sup>mm</sup> RX815 PLATE (2095-T8) (0.5" X 24" X 48")**

#### **INTRODUCTION**

The Reynold's 2095-T8 0.5-inch plates were received the first quarter of 1991. The 2095 was received in the T8 condition.

#### **TESTING**

Basic mechanical properties (tension, compression, bearing, etc) were tested according to ASTM standards, unless otherwise specified. General Dynamics generated hardness and conductivity data. Constant amplitude fatigue crack growth tests were conducted according to ASTM E647 standard. Northrop Corporation performed constant amplitude fatigue crack growth test using K controlled methods. A T-38 LIF (lead-in-fighter) spectrum test was performed by Northrop Corporation. The spectrum specimen was not precracked but contained a countersunk hole to simulate a crack initiating from a fastener hole. The Army evaluated the ballistic performance of the material. The Army and Northrop Corporation have corrosion tests in progress.

TABLE 11

**TENSILE RESULTS AT t/2 LOCATION FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCDONNELL DOUGLAS, MO	RT	LONG	89.7	85.7	12.0	23.7	10.9
			88.4	84.3	12.0	19.7	10.8
			86.8	81.1	12.0	26.4	11.4
SUNDSTRAND	RT	LONG	89.4	83.4	13.1	19.2	
			89.4	81.2	12.8	20.1	
			89.9	83.7	13.0	19.3	
ARMY-MTL	RT	LONG	88.6	81.9	12.9		10.8
			88.2	81.3	11.7		10.9
			87.7	80.4	12.9		10.4
GENERAL DYNAMICS	RT	LONG	88.1	82.5	10.7	17.1	11.0
			89.2	84.9	11.0	21.3	11.0
			89.1	84.6	10.0	17.6	11.2
NASA-LANGLEY	RT	LONG	88.0	81.2	12.3		11.2
			84.9	75.6	9.6		11.3
			85.0	77.2	9.6		11.3
NORTHROP	RT	LONG	89.7	83.6	13.9		11.5
			88.1	80.6	13.0		11.1
			89.0	81.8	13.6		11.0
AIR FORCE(*)	RT	LONG	89.4	83.1	7.4	27.0	
MCDONNELL DOUGLAS, CA	RT	LONG	84.0	77.9	12.0		
			82.5	76.0	13.0		
			82.7	77.1	10.0		
AVERAGE			87.6	81.3	11.7	21.1	11.1
STANDARD DEVIATION			2.3	2.9	1.6	3.5	0.3

(\*): TEST SECTION DIAMETER = 0.16"

TABLE I2

**TENSILE RESULTS AT t/2 LOCATION FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCDONNELL DOUGLAS, MO	RT	L TRANS	87.0 87.0 86.8	80.8 81.1 80.8	11.0 11.0 11.0	23.8 26.8 28.4	11.1 10.8 10.9
SUNDSTRAND	RT	L TRANS	86.3 85.8 86.2	79.0 78.3 79.2	12.0 12.7 13.4	25.1 25.7 27.3	
ARMY-MTL	RT	L TRANS	84.7 85.6 84.9	75.4 76.8 75.7	14.1 13.6 15.0		10.8 10.2 10.7
GENERAL DYNAMICS	RT	L TRANS	84.0 86.1 83.8	75.6 79.1 75.4	11.4 11.0 11.0	21.9 22.1 29.7	11.0 10.7 10.8
NASA-LANGLEY	RT	L TRANS	84.8 87.2 87.3	76.4 80.1 80.3		13.1 9.1 14.5	11.3 11.1 11.2
NORTHROP	RT	L TRANS	85.7 87.0 85.2	75.9 78.5 75.3	14.7 14.6 15.5		11.6 11.6 11.1
AIR FORCE(*)	RT	L TRANS	88.9	82.4	8.8	31.0	
MCDONNELL DOUGLAS, CA	RT	L TRANS	81.2 80.5 81.8	71.7 71.0 73.0	14.5 14.5 14.0		
		AVERAGE	85.4	77.4	12.8	23.0	11.0
		STANDARD DEVIATION	2.1	3.1	1.9	6.8	0.4

(\*): TEST SECTION DIAMETER = 0.16"

TABLE I3

**TENSILE RESULTS AT t/2 LOCATION FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCDONNELL	RT	45	77.0	70.6	14.0	36.6	11.4
DOUGLAS			77.2	70.1	16.0	39.1	10.9
			76.3	69.2	17.0	39.3	10.8
AIR FORCE(*)	RT	45	75.5	69.0	8.9	41.7	9.9
		AVERAGE	76.5	69.7	14.0	39.2	10.8
		STANDARD DEVIATION	0.8	0.8	3.6	2.1	0.6

(\*): TEST SECTION DIAMETER = 0.16"

TABLE I4

**TENSILE RESULTS AT t/2 LOCATION FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	-321(*)	LONG	108.0	97.5		22.0	12.0
		L TRANS	104.0	93.8	9.6	26.0	11.7
	-150	45	95.4	89.9	12.6	25.0	11.0
	-100(*)	LONG	92.3	86.2	8.8	27.0	11.0
		45	78.7	71.5	11.4	21.6	11.5
		L TRANS	91.9	85.0	8.0	26.0	
	-40	45	90.2	83.1	12.3	25.3	10.1
	0	45	89.2	82.2	11.1	22.6	10.0
	150	45	87.5	82.9	11.4	29.2	11.4
			88.7	84.8	11.9	27.7	11.4
	200	45	78.9	78.1	16.4	47.3	10.7
			79.7	78.6	17.2	47.8	11.5

(\*): TEST SECTION DIAMETER = 0.16"

TABLE 15

TENSILE RESULTS AT t/2 LOCATION FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")  
(1000 HR EXPOSURE @ 350F)

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	45	70.4	58.3	8.1	22.9	11.2
			70.1	58.0	8.2	23.8	11.3
		AVERAGE	70.3	58.1	8.2	23.3	11.2
		STANDARD DEVIATION	0.2	0.2	0.1	0.6	0.1

TABLE 16

**COMPRESSION RESULTS AT t/2 LOCATION FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")**

<b>COMPANY</b>	<b>TEST TEMPERATURE (DEGREES F)</b>	<b>ORIENTATION</b>	<b>COMPRESSIVE YIELD STRENGTH (KSI)</b>	<b>COMPRESSIVE MODULUS (MSI)</b>
<b>MCDONNELL DOUGLAS, MO</b>	<b>RT</b>	<b>LONG</b>	<b>73.8 75.3 76.1</b>	<b>11.1 10.9 11.1</b>
<b>SUNDSTRAND</b>	<b>RT</b>	<b>LONG</b>	<b>73.1 73.3 73.8</b>	<b>12.0 11.8 11.7</b>
<b>GENERAL DYNAMICS</b>	<b>RT</b>	<b>LONG</b>	<b>77.0 79.0 80.0</b>	<b>11.3 11.6 11.4</b>
<b>NASA-LANGLEY</b>	<b>RT</b>	<b>LONG</b>	<b>62.3</b>	<b>11.4</b>
<b>NORTHROP</b>	<b>RT</b>	<b>LONG</b>	<b>70.9 72.2 76.7</b>	<b>12.2 12.1 11.9</b>
<b>MCDONNELL DOUGLAS, CA</b>	<b>RT</b>	<b>LONG</b>	<b>68.1 69.1 69.6</b>	<b>11.0 11.5 11.7</b>
<b>AVERAGE</b>			<b>73.1</b>	<b>11.6</b>
<b>STANDARD DEVIATION</b>			<b>4.5</b>	<b>0.4</b>

**TABLE I7**  
**COMPRESSION RESULTS AT t/2 LOCATION FOR REYNOLDS**  
**2095-T8 PLATE (0.5" X 24" X 48")**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCDONNELL DOUGLAS, MO	RT	L TRANS	79.5	11.8
			78.5	11.8
			79.1	11.6
SUNDSTRAND	RT	L TRANS	79.4	11.6
			79.0	11.5
			77.6	12.7
GENERAL DYNAMICS	RT	L TRANS	79.2	11.4
			80.6	11.6
			80.4	12.0
NASA-LANGLEY	RT	L TRANS	75.1	11.4
			77.0	11.5
			76.0	11.4
NORTHROP	RT	L TRANS	79.4	11.9
			75.9	12.1
			73.5	12.2
MCDONNELL DOUGLAS, CA	RT	L TRANS	72.9	14.0
			72.3	13.5
			73.2	13.8
AVERAGE			77.1	12.1
STANDARD DEVIATION			2.8	0.8

TABLE 18

COMPRESSION RESULTS AT t/2 LOCATION FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCDONNELL	RT	45	70.5	11.1
DOUGLAS			70.3	11.0
			72.2	10.9
		AVERAGE	71.0	11.0
		STANDARD DEVIATION	1.0	0.1

TABLE 19

COMPRESSION RESULTS AT t/2 LOCATION FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE ULT STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
ARMY-MTL	RT	LONG	111.2	
			107.2	
			110.7	
		AVERAGE	109.7	
		STANDARD DEVIATION	2.2	
ARMY-MTL	RT	L TRANS	115.4	
			119.0	
			114.7	
		AVERAGE	116.4	
		STANDARD DEVIATION	2.3	

**TABLE I10**

**PIN SHEAR RESULTS FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<b>ARMY-MTL</b>	<b>LONG</b>	<b>49.5</b>
		<b>48.8</b>
		<b>49.7</b>
<b>NORTHROP</b>	<b>LONG</b>	<b>45.7</b>
		<b>46.6</b>
		<b>46.0</b>
	<b>AVERAGE</b>	<b>47.7</b>
	<b>STANDARD DEVIATION</b>	<b>1.8</b>

**TABLE I11**

**RIVET SHEAR RESULTS FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<b>ARMY-MTL</b>	<b>L TRANS</b>	<b>49.0</b>
		<b>48.5</b>
		<b>47.7</b>
	<b>AVERAGE</b>	<b>48.4</b>
	<b>STANDARD DEVIATION</b>	<b>0.7</b>

**TABLE I12**

**TORSIONAL SHEAR RESULTS FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<hr/>		
<b>SUNDSTRAND</b>	<b>LONG</b>	<b>47.1</b>
		<b>46.4</b>
		<b>45.1</b>
	<b>AVERAGE</b>	<b>46.2</b>
	<b>STANDARD DEVIATION</b>	<b>1.0</b>
<b>SUNDSTRAND</b>	<b>L TRANS</b>	<b>45.4</b>
		<b>45.1</b>
		<b>46.8</b>
	<b>AVERAGE</b>	<b>45.8</b>
	<b>STANDARD DEVIATION</b>	<b>0.9</b>

**TABLE I13**

**AMSLER DOUBLE SHEAR RESULTS FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<hr/>		
<b>NASA-LANGLEY</b>	<b>L-S</b>	<b>44.4</b>
		<b>46.3</b>
		<b>47.7</b>
	<b>AVERAGE</b>	<b>46.1</b>
	<b>STANDARD DEVIATION</b>	<b>1.7</b>
<b>NASA-LANGLEY</b>	<b>T-S</b>	<b>47.5</b>
		<b>45.6</b>
		<b>45.0</b>
	<b>AVERAGE</b>	<b>46.0</b>
	<b>STANDARD DEVIATION</b>	<b>1.3</b>

TABLE I14

**BEARING RESULTS FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")**

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
MCDONNELL DOUGLAS, MO	LONG	1.5		128.0		106.0
				119.0		100.0
				122.0		103.0
NASA-LANGLEY	LONG	1.5		123.1		99.2
				119.4		98.4
				120.6		100.3
MCDONNELL DOUGLAS, CA	LONG	1.5		120.2		102.1
				121.1		101.9
				121.1		101.5
AVERAGE				121.6		101.4
STANDARD DEVIATION				2.7		2.3

TABLE I15

**BEARING RESULTS FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")**

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
MCDONNELL	45	1.5		128.0		106.0
DOUGLAS, MO				131.0		110.0
				135.0		111.0
AVERAGE				131.3		109.0
STANDARD DEVIATION				3.5		2.6

TABLE I16

**BEARING RESULTS FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")**

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
MCDONNELL DOUGLAS, MO	L TRANS	1.5		125.0		106.0
				129.0		105.0
				131.0		107.0
NASA-LANGLEY	L TRANS	1.5		122.2		98.4
				124.2		101.6
				124.7		99.4
MCDONNELL DOUGLAS, CA	L TRANS	1.5		121.7		100.4
				121.7		98.3
				120.5		97.3
AVERAGE				124.4		101.5
STANDARD DEVIATION				3.5		3.6

TABLE I17

**BEARING RESULTS FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")**

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
MCDONNELL	LONG	2.0		164.0		128.0
DOUGLAS, MO				159.0		131.0
				158.0		130.0
NASA-LANGLEY	LONG	2.0				114.5
				148.0		111.0
				146.7		112.3
NORTHROP	LONG	2.0		156.4		116.5
				154.3		114.3
				153.6		113.7
MCDONNELL	LONG	2.0		157.5		119.6
DOUGLAS, CA				156.5		124.1
				157.4		120.2
AVERAGE				155.6		119.6
STANDARD DEVIATION				4.9		7.1

TABLE I18

**BEARING RESULTS FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")**

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
MCDONNELL	45	2.0	172.0		141.0	
DOUGLAS, MO			166.0		136.0	
			169.0		138.0	
AVERAGE			169.0		138.3	
STANDARD DEVIATION			3.0		2.5	

TABLE I19

**BEARING RESULTS FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")**

COMPANY	ORIENTATION	e/D	BEARING	
			ULT. STR. (KSI)	YIELD STR. (KSI)
MCDONNELL DOUGLAS, MO	L TRANS	2.0	163.0	132.0
			160.0	137.0
			166.0	137.0
NASA-LANGLEY	L TRANS	2.0		116.4
			154.5	116.6
			154.5	116.1
NORTHROP	L TRANS	2.0	158.7	121.1
			160.4	120.6
			160.2	128.5
MCDONNELL DOUGLAS, CA	L TRANS	2.0	155.4	122.1
			158.9	124.6
			156.8	122.9
AVERAGE			158.9	124.6
STANDARD DEVIATION			3.6	7.5

**TABLE 120**

**FRACTURE TOUGHNESS RESULTS FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")**

COMPANY	ORIENTATION	KIC		Kq	COMMENT
		(KSI in <sup>0.5</sup> )	(KSI in <sup>0.5</sup> )		
MCDONNELL	L-T			26.3	(1)
DOUGLAS				22.8	(2)
SUNDSTRAND	L-T	30.2			
		30.0			
ARMY-MTL	L-T	26.8			
				37.3	(2), (3)
				33.3	(2)
				36.4	(2), (3)
				33.7	(2)
GENERAL	L-T			33.5	(2)
DYNAMICS				30.7	(2)
				30.1	(2)
NASA-LANGLEY	L-T	27.0			
				25.3	(2)
NORTHROP	L-T			37.7	(3)
				40.4	(3)
				43.3	(3)
AVERAGE		28.5		33.1	
STANDARD DEVIATION		1.8		6.0	

(1): INVALID DUE TO SURFACE CRACK LENGTH MEASUREMENTS  
EXCEEDED 10% OF AVERAGE CRACK LENGTH

(2): INVALID DUE TO  $P_{max}/P_q > 1.10$

(3): INVALID DUE TO  $a \text{ \& } B > 2.5(Kq/Y_S)^{2/3}$

TABLE I21

**FRACTURE TOUGHNESS RESULTS FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")**

COMPANY	ORIENTATION	K <sub>IC</sub> (KSI in <sup>0.5</sup> )	K <sub>q</sub> (KSI in <sup>0.5</sup> )	COMMENT
MCDONNELL DOUGLAS	T-L	29.6	25.8	(1)
SUNDSTRAND	T-L	29.1 29.0		
ARMY-MTL	T-L		40.2 35.6 35.0 35.9 36.9 35.5	(2), (3) (2) (2), (3) (2), (3) (2), (3) (3)
GENERAL DYNAMICS	T-L	31.4	29.4 29.2	(2) (2)
NASA-LANGLEY	T-L	24.4		
NORTHROP	T-L		38.7 38.3 37.9	(3) (3) (3)
	AVERAGE	28.7	34.9	
	STANDARD DEVIATION	2.6	4.4	

(1): INVALID DUE TO SURFACE CRACK LENGTH MEASUREMENTS  
EXCEEDED 10% OF AVERAGE CRACK LENGTH

(2): INVALID DUE TO  $P_{max}/P_q > 1.10$

(3): INVALID DUE TO  $a \text{ \& } B > 2.5(K_q/Y_S)^{**2}$

**TABLE 122**

**FRACTURE TOUGHNESS RESULTS FOR REYNOLDS  
2095-T8 PLATE (0.5" X 24" X 48")**

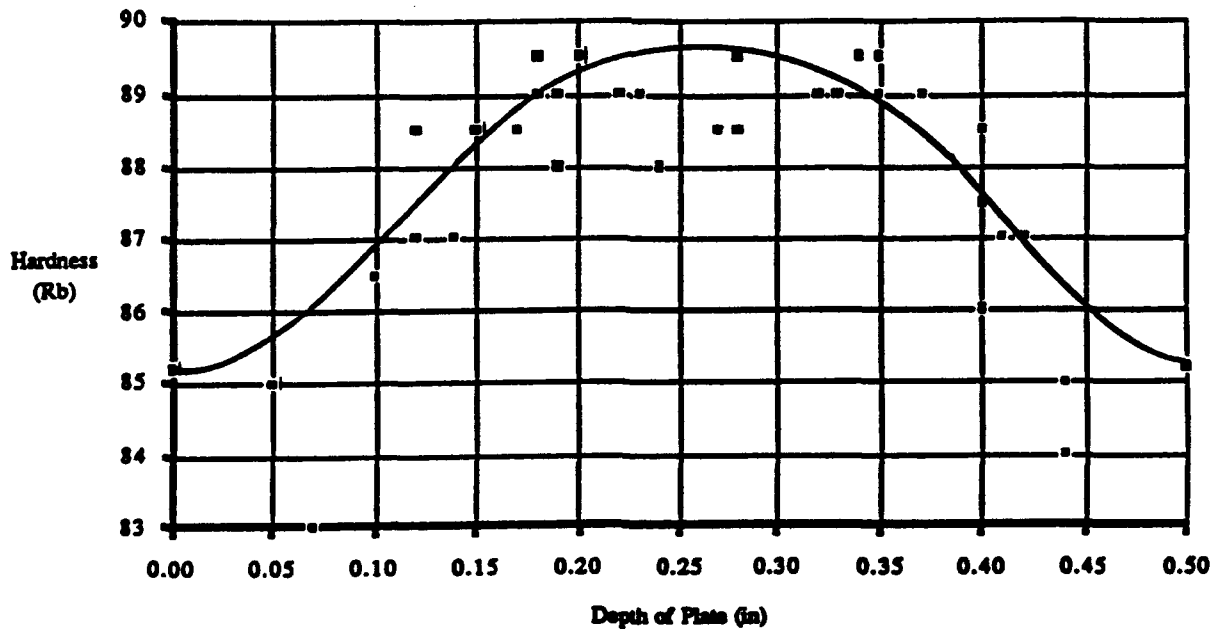
COMPANY	ORIENTATION	K <sub>IC</sub>	K <sub>q</sub>	COMMENT
		(KSI in <sup>0.5</sup> )	(KSI in <sup>0.5</sup> )	
MCDONNELL	45		25.4	(1)
DOUGLAS		23.6		

(1): INVALID DUE TO SURFACE CRACK LENGTH MEASUREMENTS  
EXCEEDED 10% OF AVERAGE CRACK LENGTH

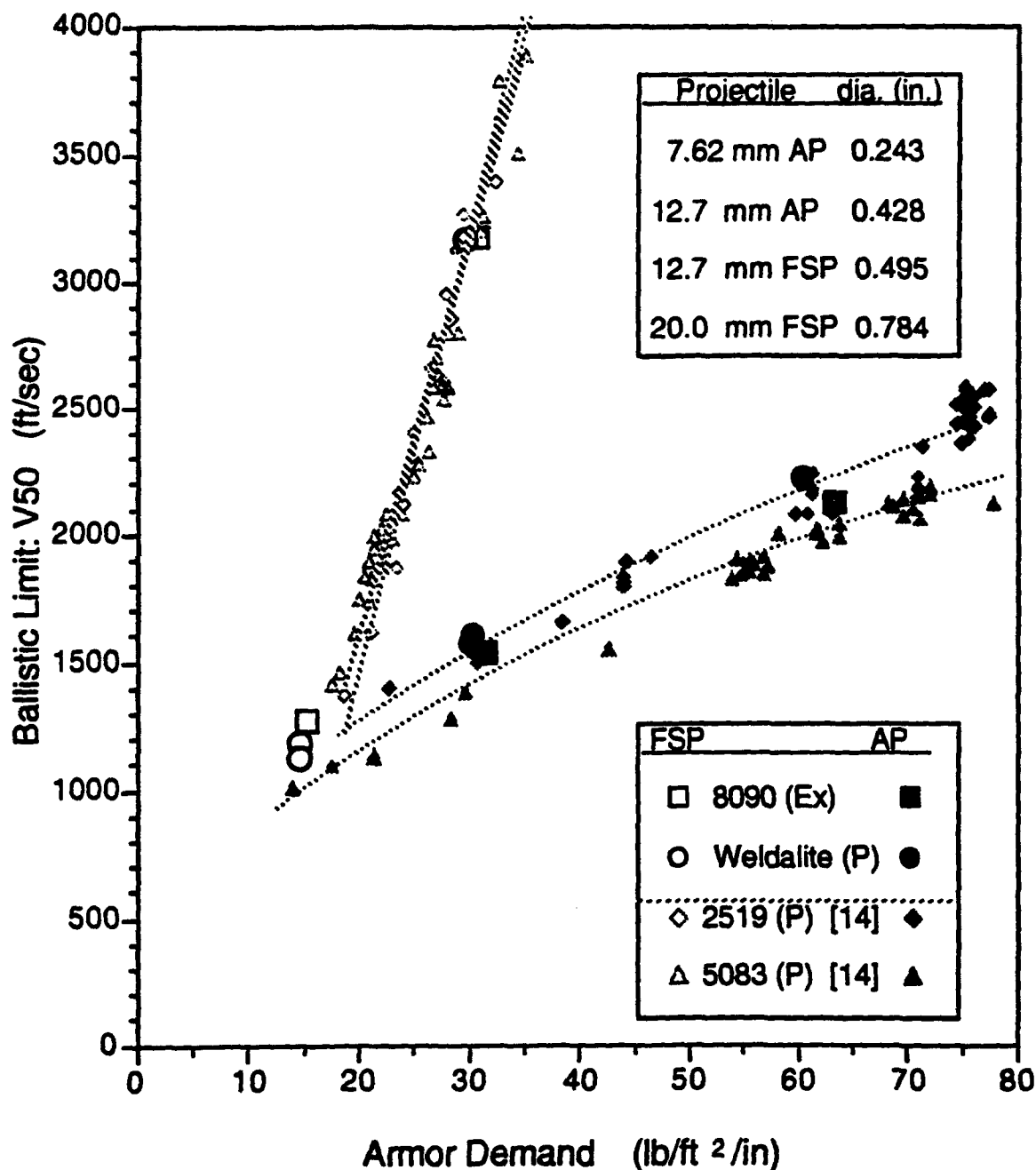
**TABLE I23**

**Hardness & Conductivity Results for 2095-T8  
0.5 Inch Plate. General Dynamics, CA**

Alloy/Product Form	Hardness (R <sub>B</sub> Scale)	Conductivity (% IACS)
Weldalite 2095-T8 0.50 Inch Plate	See Figure	22 (a) 17 (b)
(a) as received mill surface (b) machined surface		



**Figure I1. Hardness profile through 2095-T8  
0.5 Inch Plate. General Dynamics, CA.**



Both 8090 extrusions (Ex) and Weldalite plates (P) provided enhanced ballistic performance over 2519 and 5083 Al alloys. The  $V_{50}$  ballistic limits against AP and FSP projectiles at  $0^\circ$  obliquity are plotted versus Armor demand. The Armor demand is defined as the (density  $\times$  thickness) / projectile diameter. The ballistic data for different caliber projectiles superimpose on single curves for either AP or FSP projectiles when plotted against armor demand. This technique allows designers to evaluate ballistic performance as a function of projectile type rather than for individual munitions. The AP and FSP projectile diameters are included as inserts in the plot. Ballistic data for 2519 and 5083 are included as the high and low ends of aluminum alloys currently being considered for structural armor applications. The lower set of 8090 and Weldalite data points for both AP and FSP projectiles represent 0.5 inch ballistic targets. The second series of data points for each projectile type represent stacked plates to provide 1.0 inch thickness. The ballistic limits of both AL-Li alloys are attributed to the witness plate being perforated by spalling rather than by the projectile exiting the target.

Figure I2. Ballistic limit ( $V_{50}$ ) versus Armor Demand at  $0^\circ$  obliquity against Armor Piercing (AP) and Fragment Simulating Projectiles (FSP). Army.

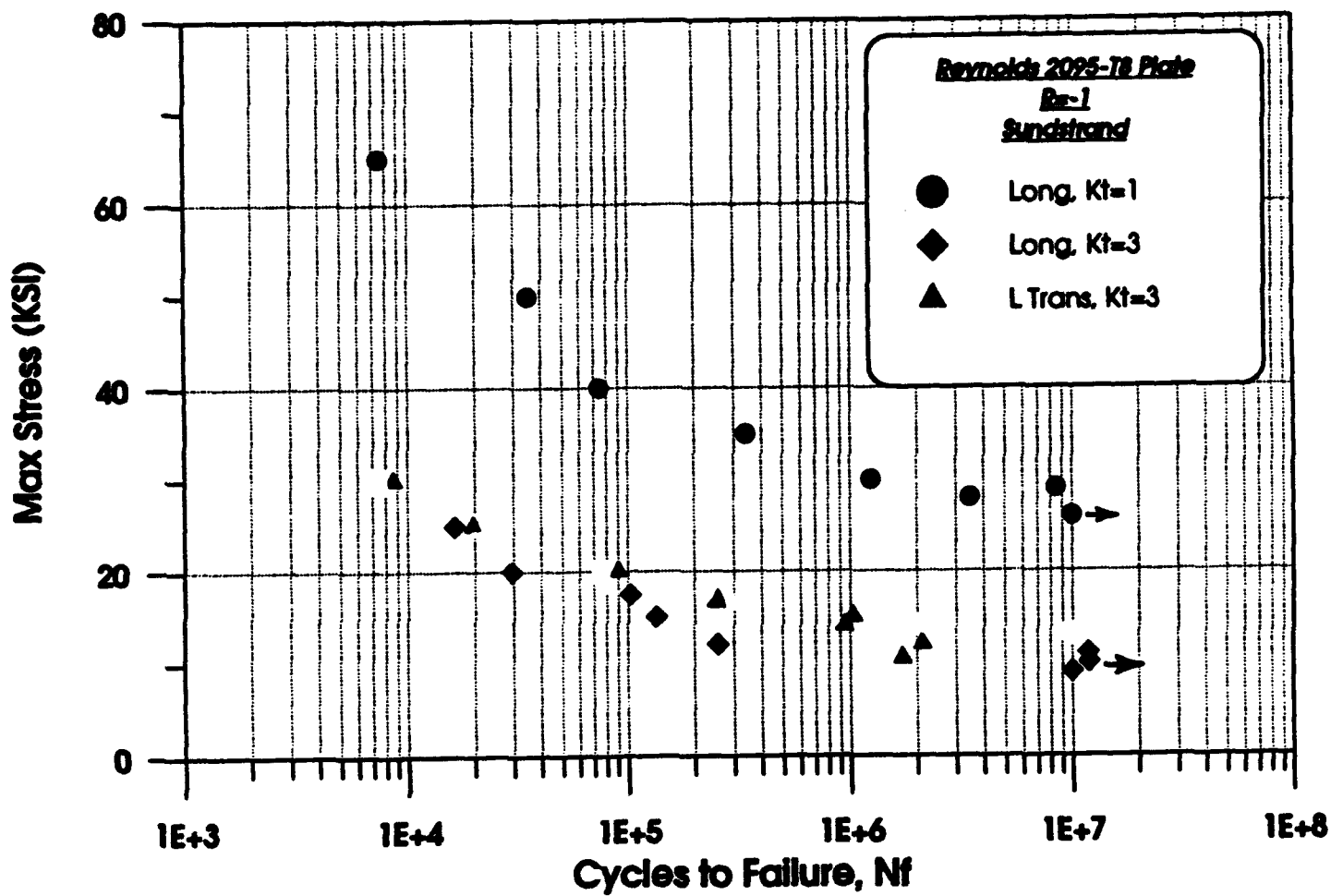


Figure I3. Fatigue Results for 2095-T8 0.5 Inch Plate ( $R = -1$ ,  $K_t = 1.0$  and  $K_t = 3.0$ ) and 2095-T6 ( $R = -1$  and  $K_t = 3$ )

TABLE I24

FATIGUE RESULTS WITH R=-1.0 AND Kt=1.0 FOR  
REYNOLDS 2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
<hr/>			
SUNDSTRAND	LONG	65.0	7,500
		50.0	34,950
		40.0	73,820
		35.0	338,910
		30.0	1,240,950
		29.0	8,461,080
		28.0	3,489,830
		26.0	10,000,000 *

(\*): RUN OUT

TABLE I25

FATIGUE RESULTS WITH R=-1.0 AND Kt=3.0 FOR  
REYNOLDS 2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
<hr/>			
SUNDSTRAND	LONG	25.0	16,300
		20.0	29,460
		17.5	102,580
		15.0	133,920
		12.0	253,810
		11.0	11,796,000 *
		10.0	11,913,000 *
		9.0	10,000,000 *

(\*): RUN OUT

TABLE I26

FATIGUE RESULTS WITH R=-1.0 AND Kt=3.0 FOR  
REYNOLDS 2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
<hr/>			
SUNDSTRAND	L TRANS	30.0	8,620
		25.0	19,690
		20.0	90,000
		17.0	254,530
		15.0	1,024,210
		14.0	943,790
		12.0	2,110,280
		10.5	1,715,500

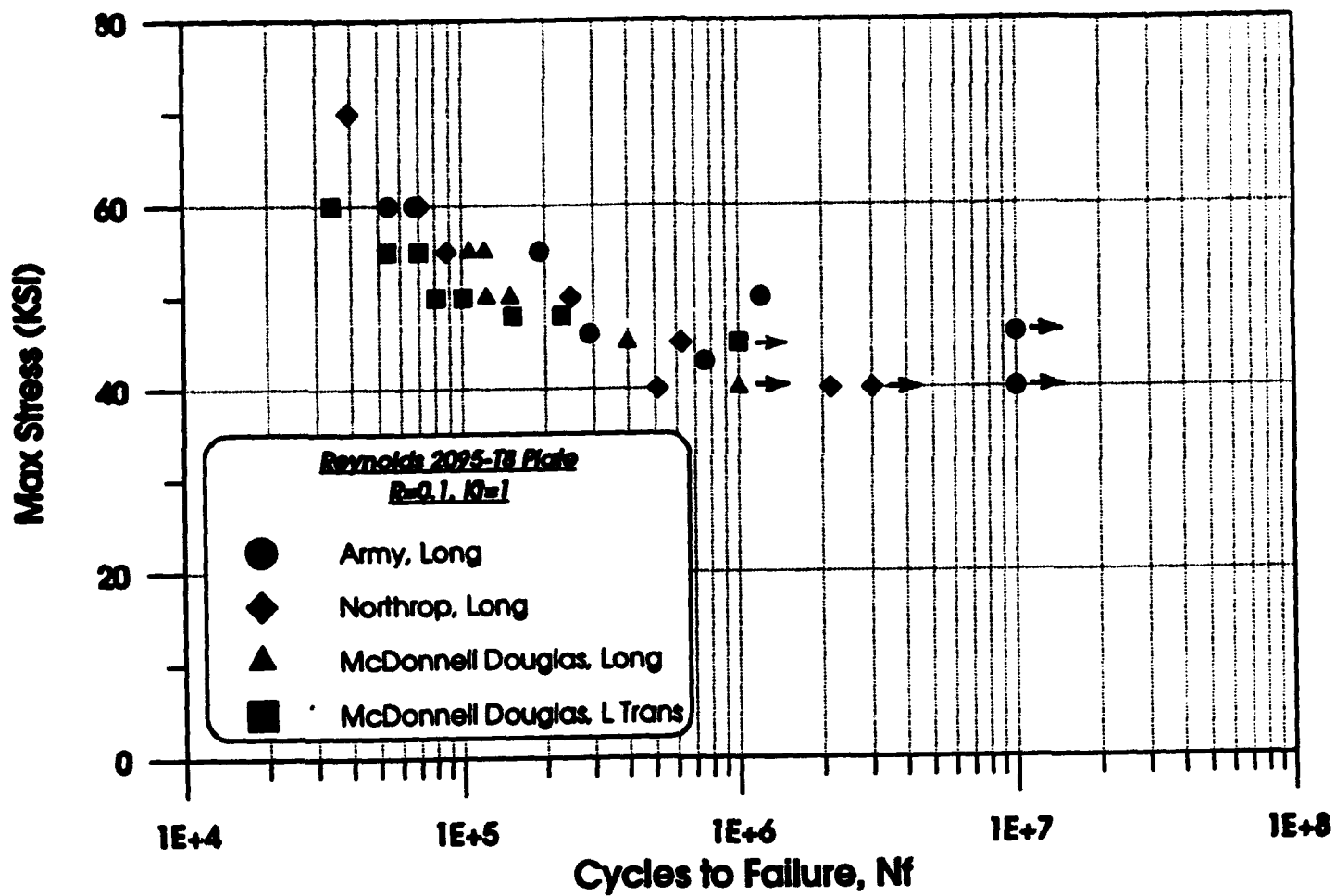


Figure I4. Fatigue Results for 2095-T8 0.5 Inch Plate ( $R=0.1$  and  $K_t=1.0$ )

TABLE I27

FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR  
REYNOLDS 2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
-----			
ARMY-MTL	LONG	60.0	54,220
		60.0	67,580
		55.0	191,520
		50.0	1,205,760
		46.0	290,042
		46.0	10,026,880 *
		43.0	754,000
		40.0	10,010,000 *
NORTHROP	LONG	70.0	39,420
		60.0	70,550
		55.0	87,944
		50.0	247,950
		45.0	623,760
		40.0	511,870
		40.0	3,000,000 *
		40.0	2,135,840
MCDONNELL DOUGLAS, CA	LONG	55.0	106,010
		55.0	120,950
		50.0	149,620
		50.0	122,970
		45.0	398,910
		45.0	398,300
		40.0	1,000,000 *
		40.0	1,000,000 *
MCDONNELL DOUGLAS, CA	L TRANS	60.0	34,170
		55.0	53,870
		55.0	69,800
		50.0	101,060
		50.0	80,470
		48.0	153,080
		48.0	229,570
		45.0	1,000,000 *
		45.0	1,000,000 *
(*) : RUN-OUT			

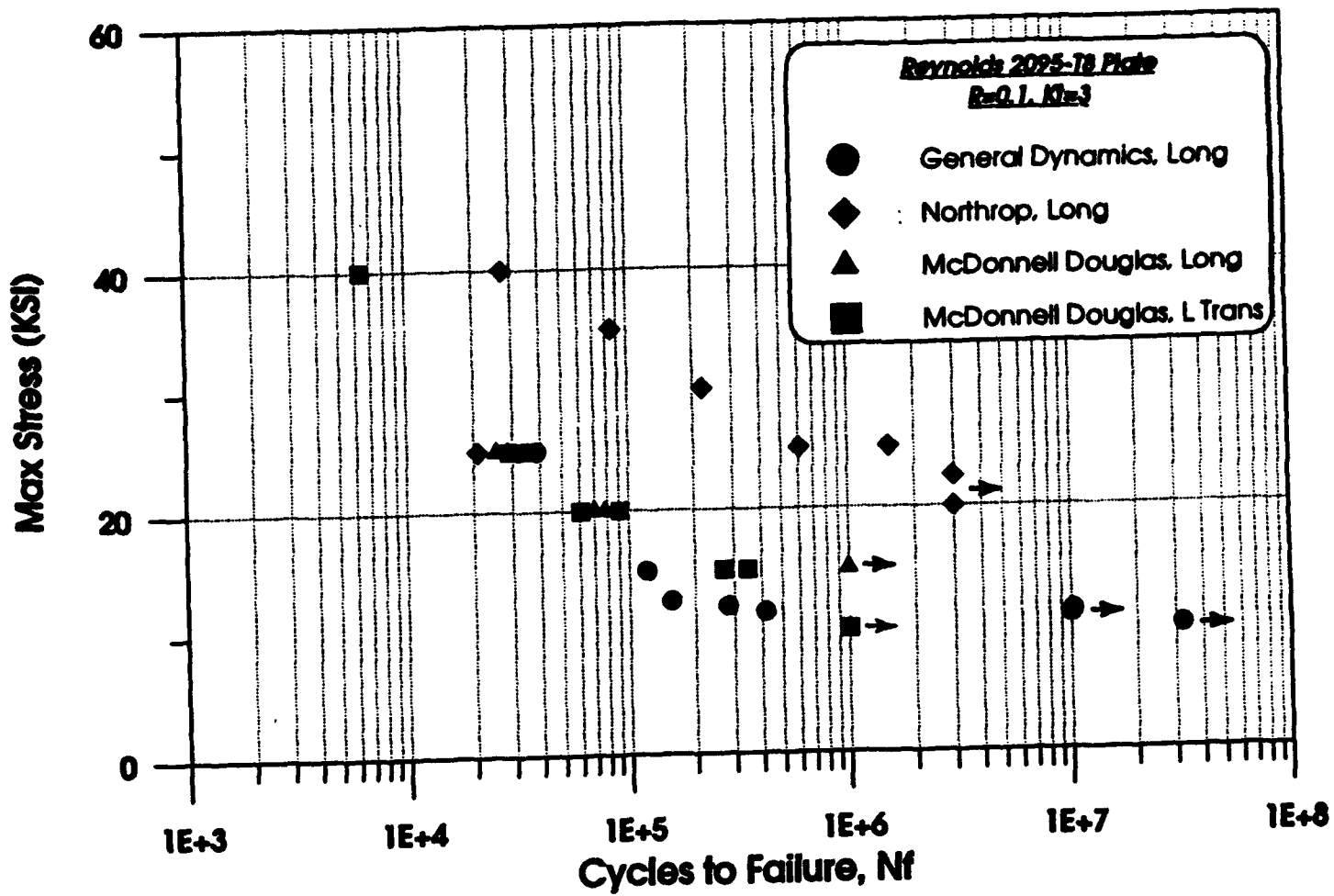


Figure I5. Fatigue Results for 2095-T8 0.5 Inch Plate ( $R = 0.1$  and  $K_t = 3$ )

TABLE I28

FATIGUE RESULTS WITH R=0.1 AND K<sub>t</sub>=3.0 FOR  
REYNOLDS 2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
<hr/>			
GENERAL DYNAMICS	LONG	25.0	38,200
		15.0	120,600
		12.5	155,500
		12.0	281,900
		11.5	417,100
		11.3	10,240,300 *
		11.0	10,000,000 *
		10.0	32,313,000 *
NORTHROP	LONG	40.0	27,530
		35.0	84,820
		30.0	220,840
		25.0	20,830
		25.0	605,470
		25.0	1,535,480
		22.5	3,000,000 *
		20.0	3,000,000 *
MCDONNELL DOUGLAS, CA	LONG	25.0	28,540
		25.0	25,320
		20.0	78,410
		20.0	69,950
		15.0	1,000,000 *
		15.0	1,000,000 *
		10.0	1,000,000 *
		10.0	1,000,000 *
MCDONNELL DOUGLAS, CA	L TRANS	40.0	6,331
		25.0	28,860
		25.0	32,940
		20.0	60,520
		20.0	91,030
		15.0	348,180
		15.0	271,490
		10.0	1,000,000 *
		10.0	1,000,000 *

(\*): RUN-OUT

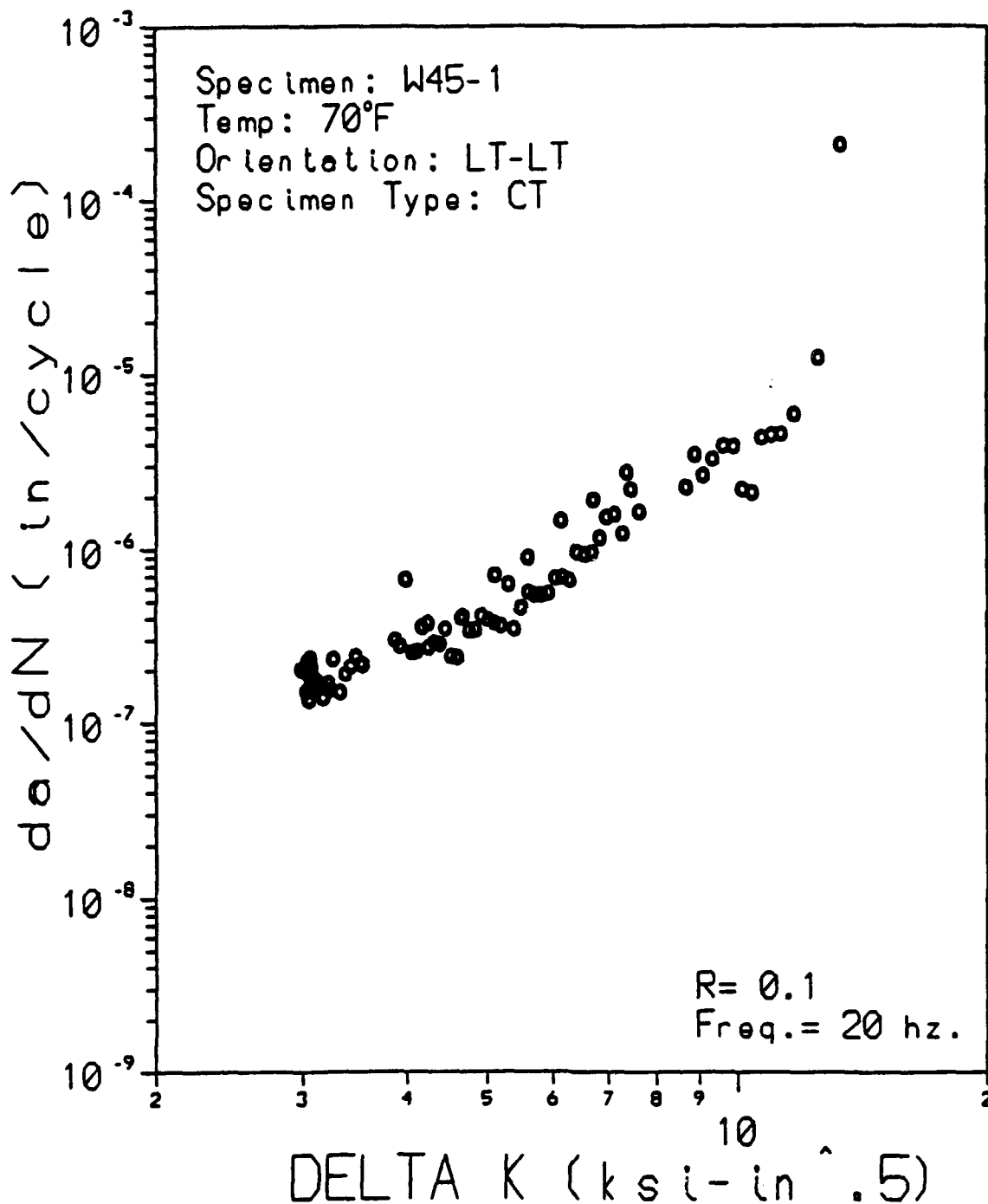


Figure I6. Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Plate (LT-LT orientation, Specimen W45-1). Air Force.

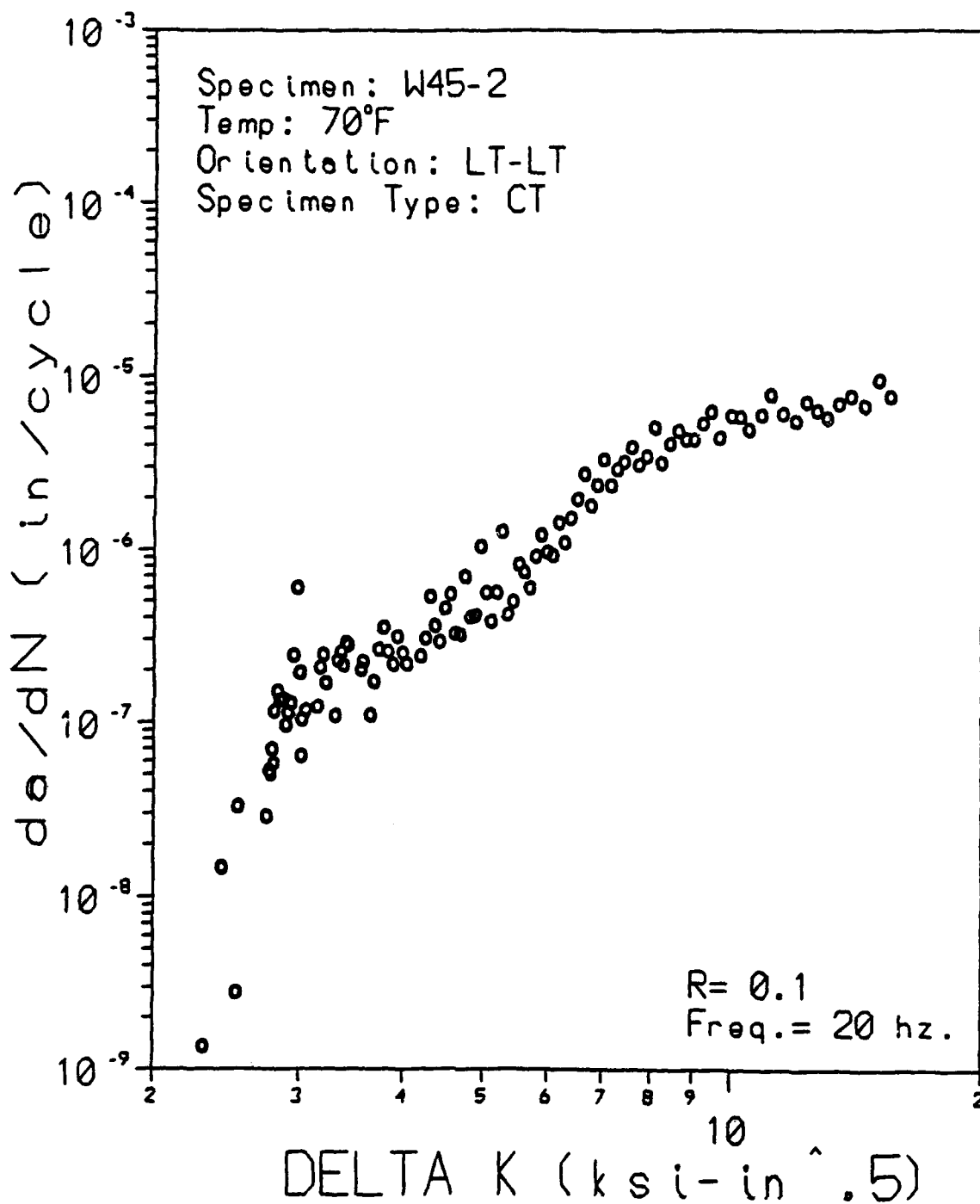


Figure I7. Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Plate (LT-LT orientation, Specimen W45-2). Air Force.

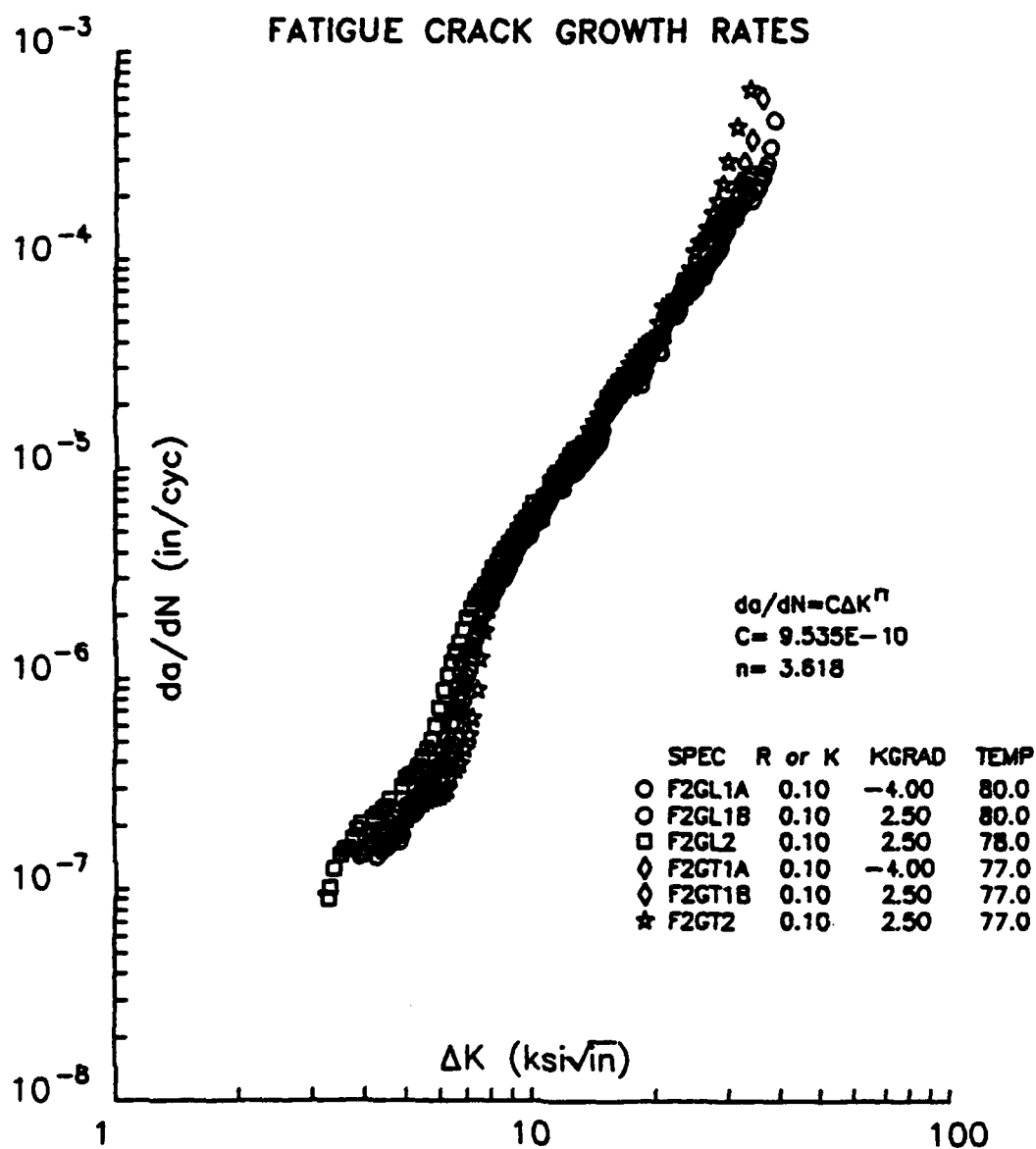


Figure I8. Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Thick Plate (L-T and T-L orientations). Northrop.

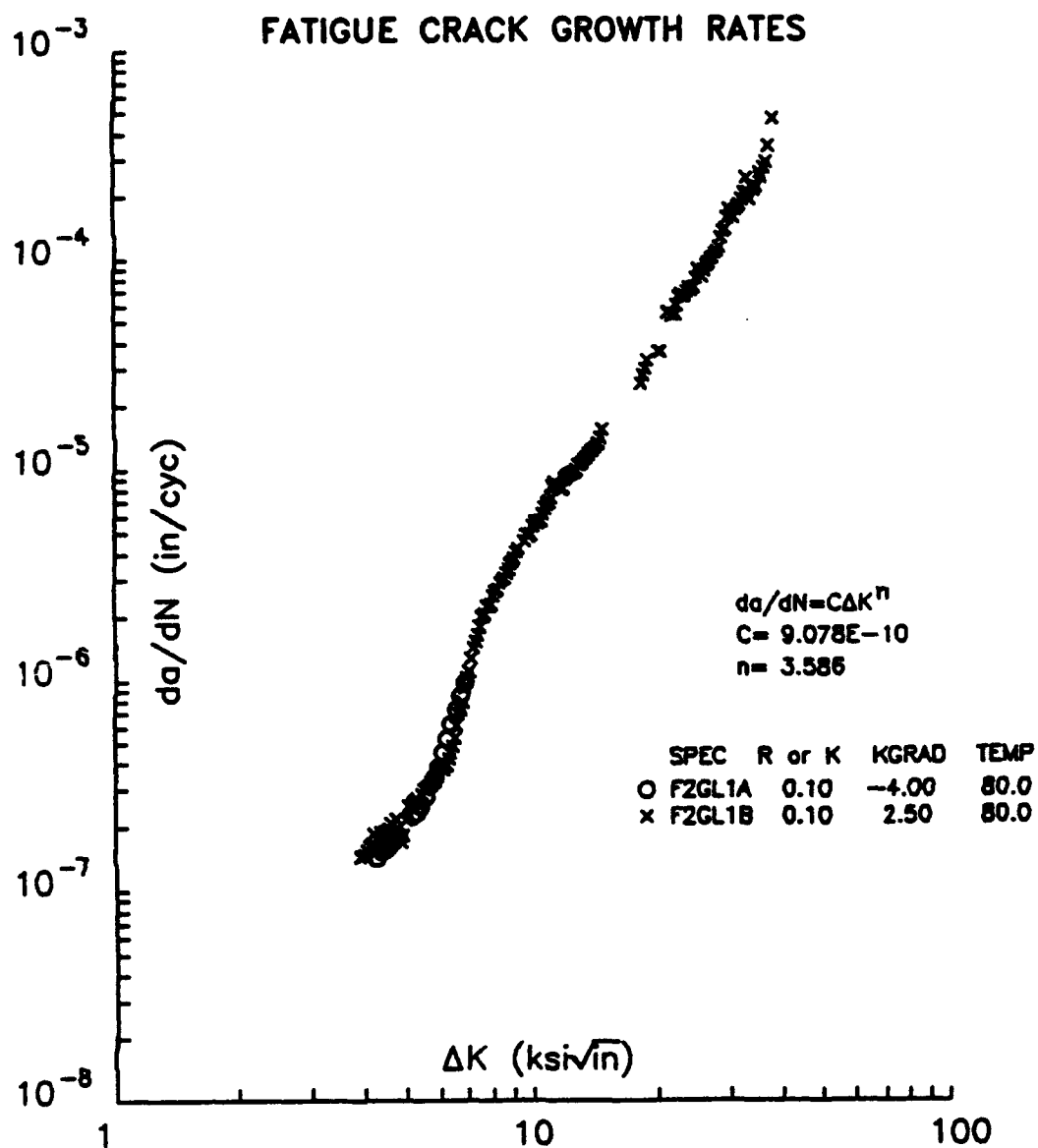


Figure I9. Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Thick Plate (L-T orientation, KGRAD - 4.00 and 2.50). Northrop.

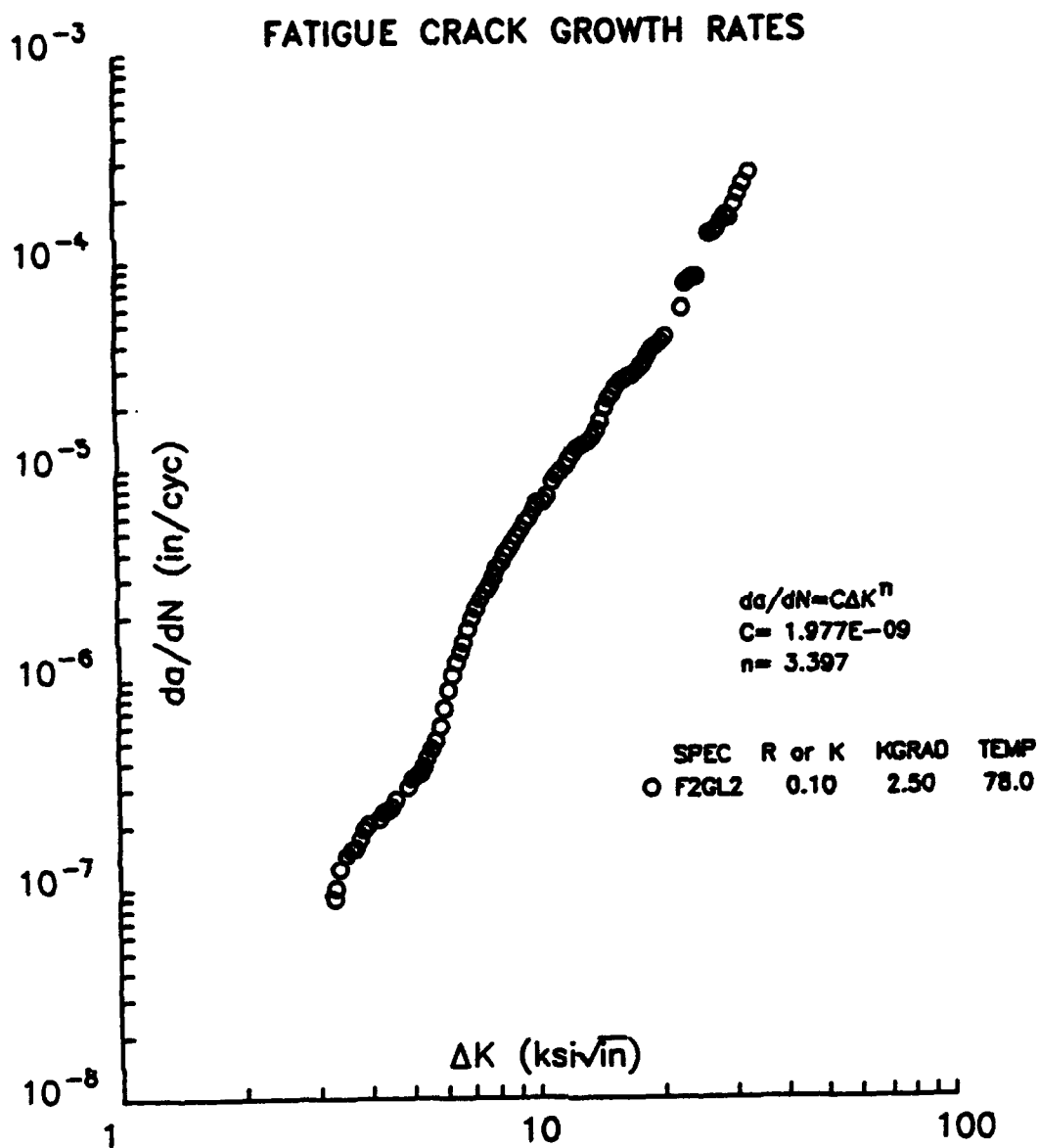


Figure I10. Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Thick Plate (L-T orientation, KGRAD 2.50). Northrop.

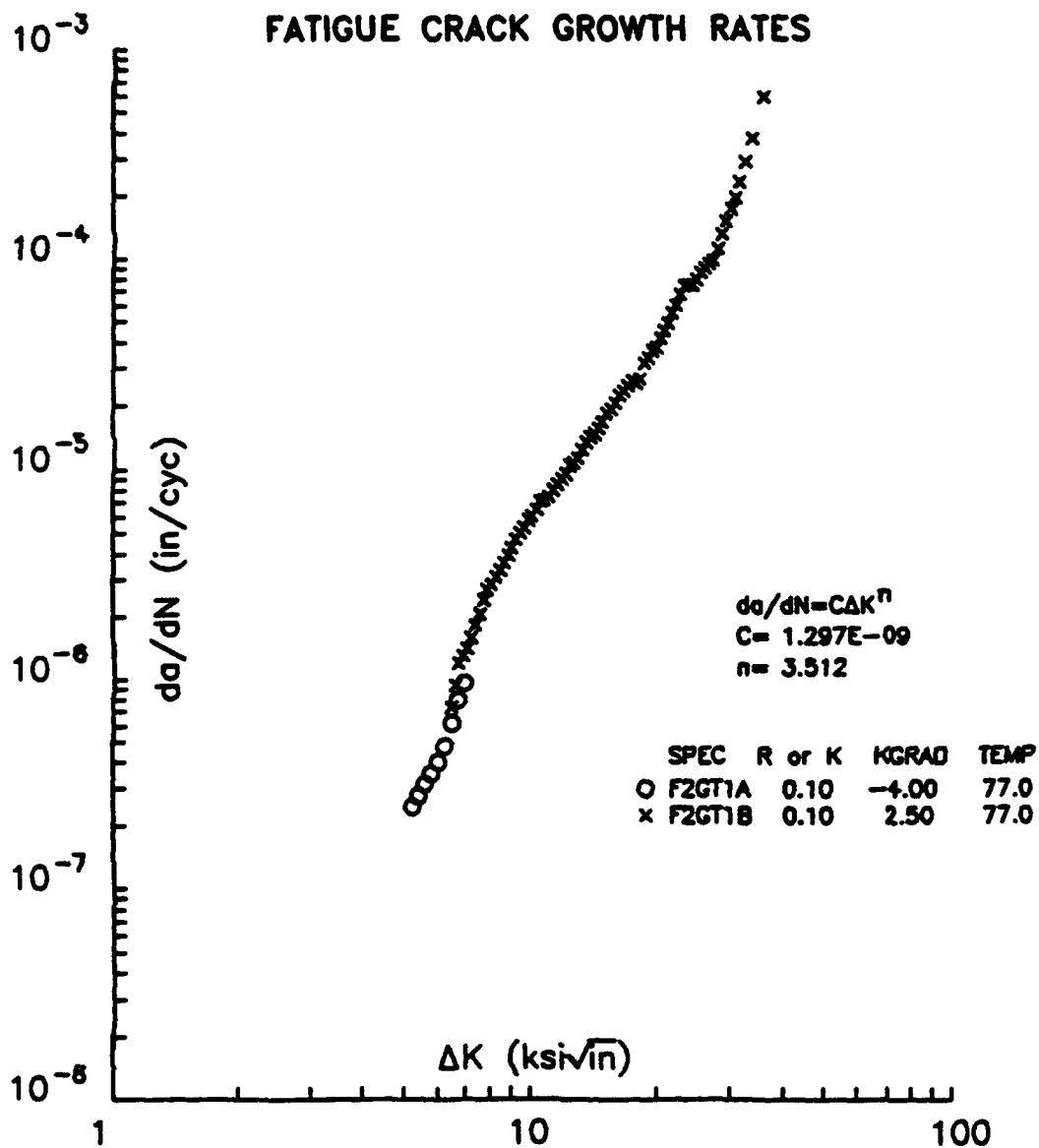
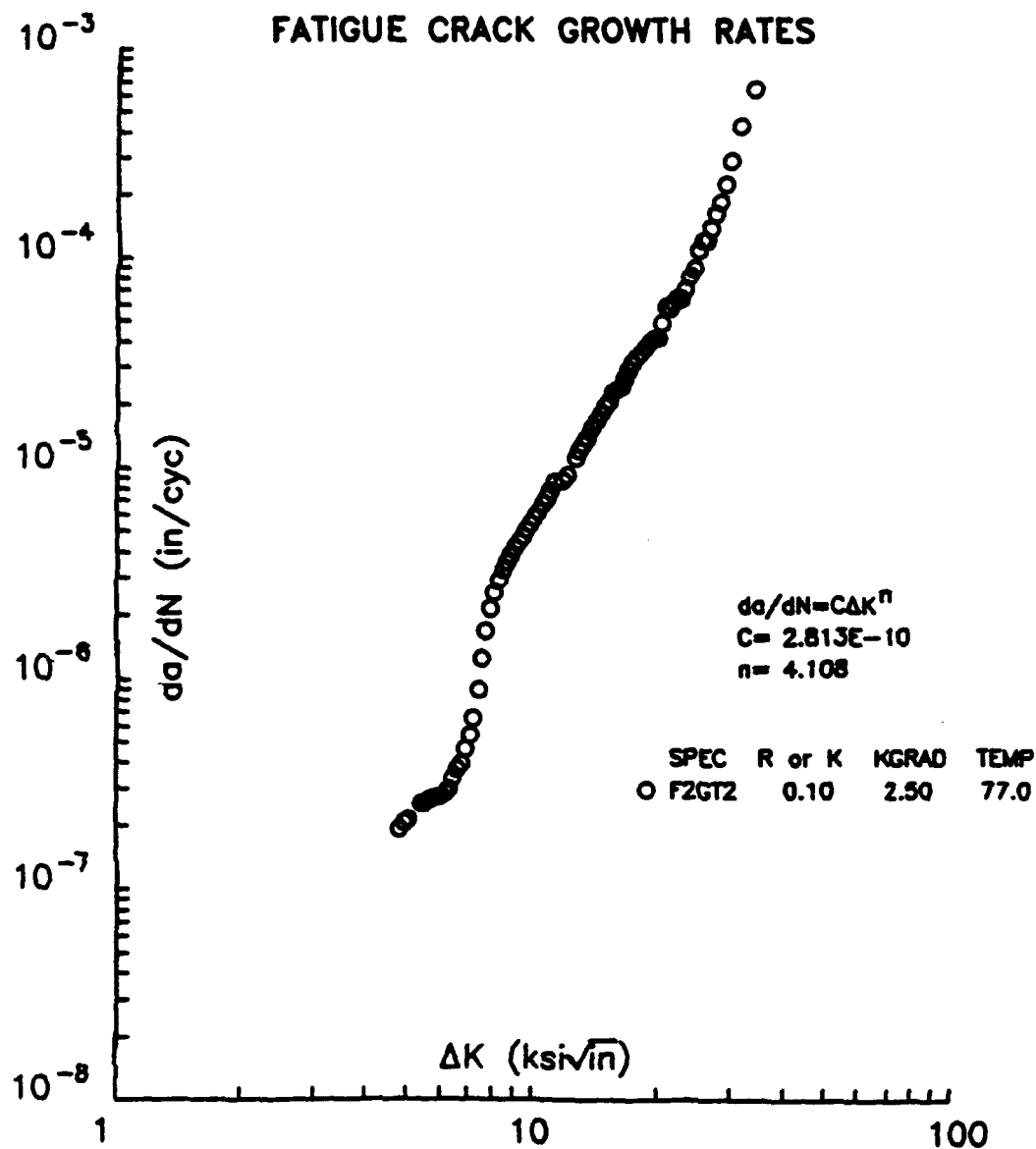
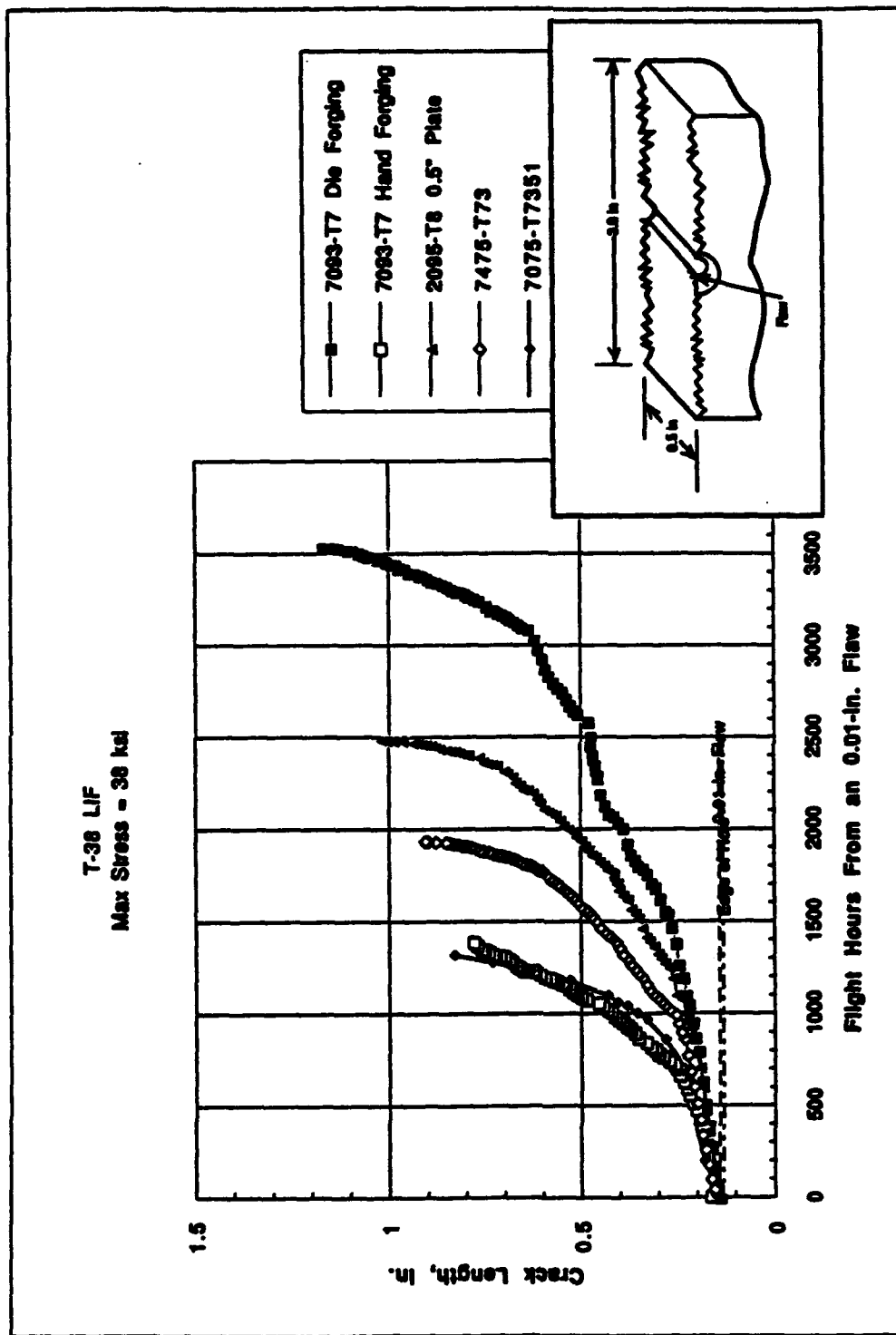


Figure I11. Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Thick Plate (T-L orientation, KGRAD - 4.00 and 2.50). Northrop.

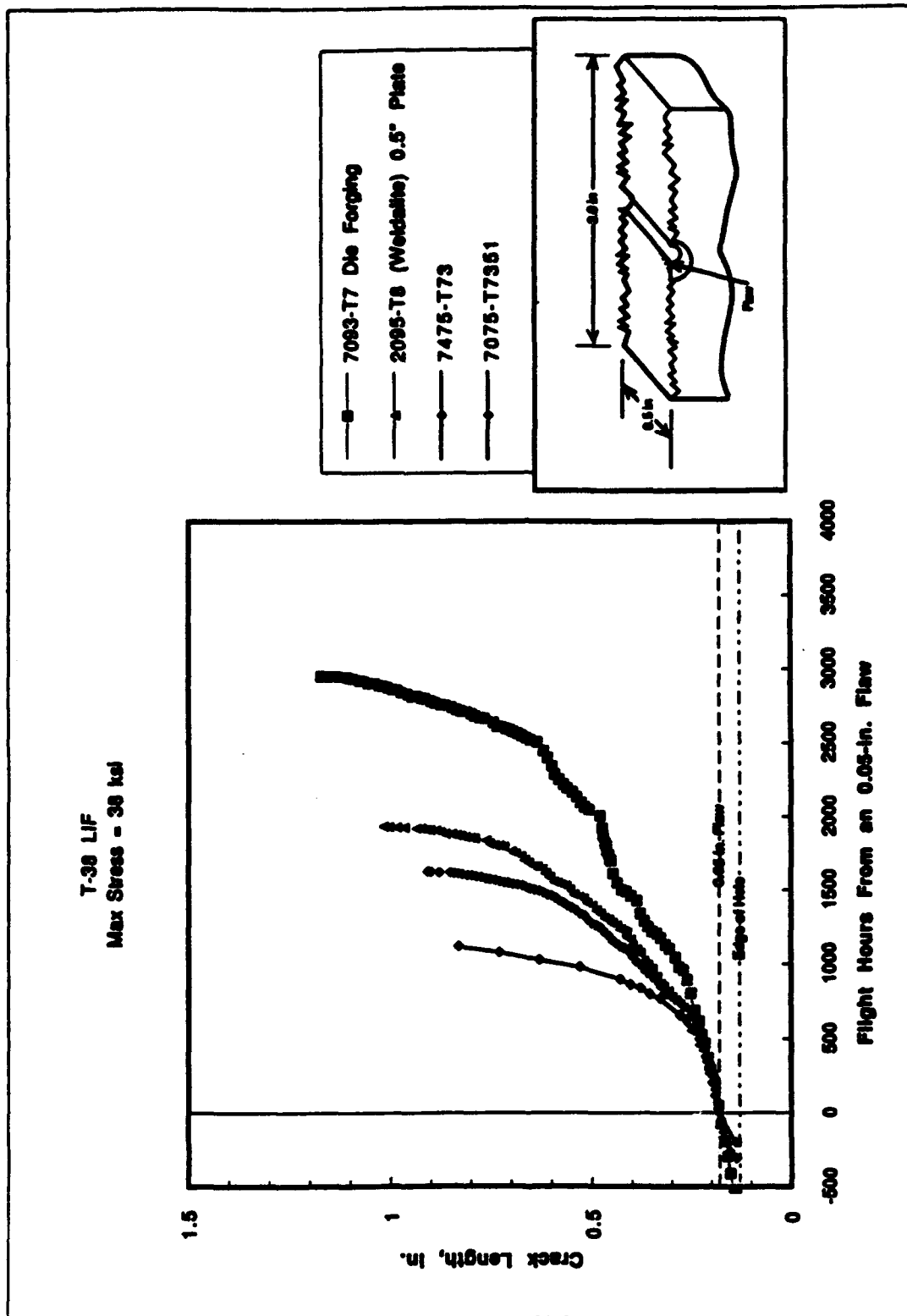


**Figure I12. Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Thick Plate (T-L orientation, KGRAD 2.50). Northrop.**



T-38 LIF a v. N 0.01" 4/24/92

Figure I13. T38 LIF Spectrum Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Plate (Max Stress = 38 Ksi, Flaw = 0.01 inch). Northrop.



T-38 LIF a v. N 0.05" 6/8/92

Figure I14. T38 LIF Spectrum Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Plate (Max Stress = 38 Ksi, Flaw = 0.05 inch). Northrop.

# T-38 LIF Spectrum Fatigue

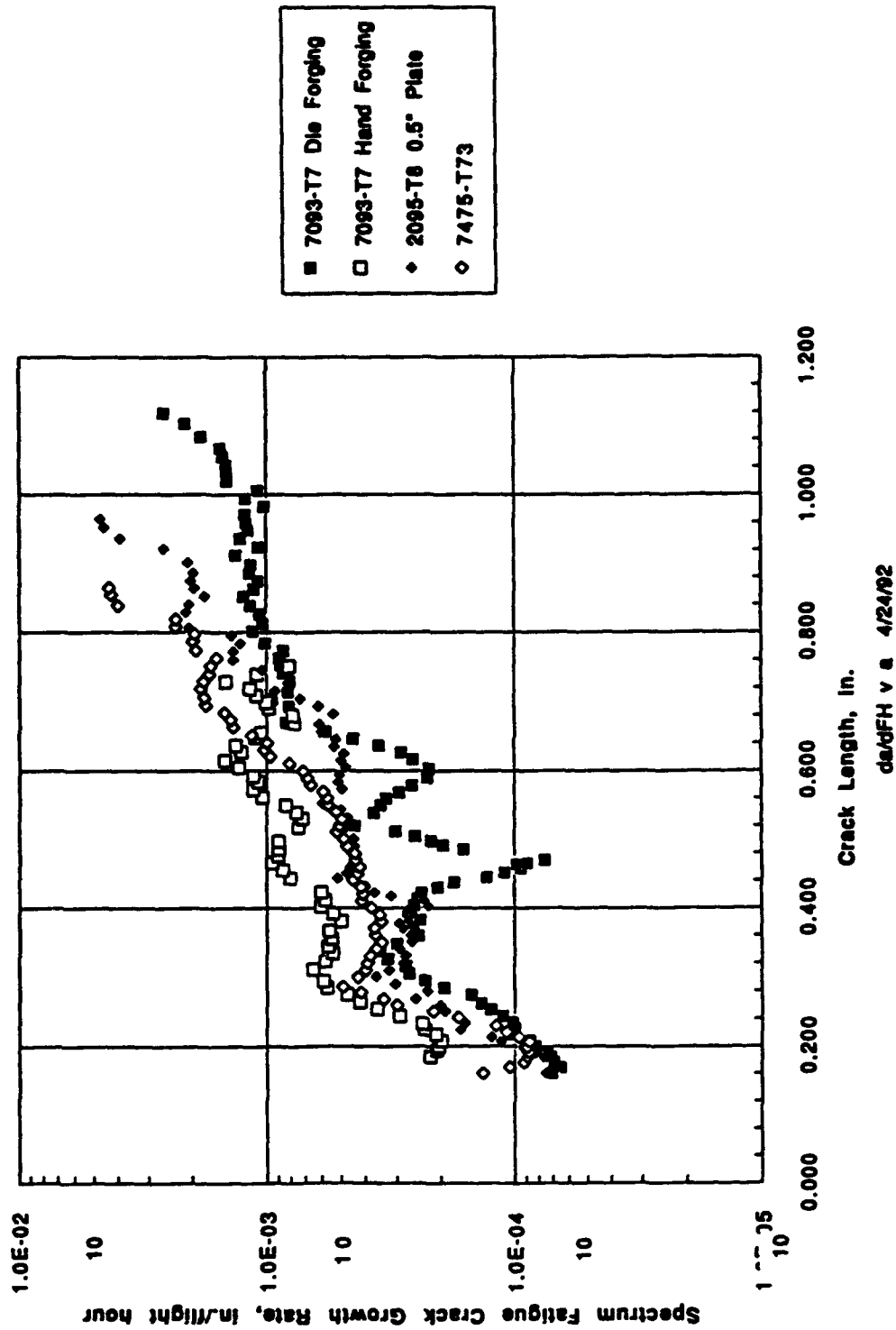


Figure I15. T38 LIF Spectrum Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Plate (Max Stress = 38 Ksi). Northrop.

## **APPENDIX J**

### **2091-T3 AND 2091-T8 0.063 INCH SHEET**

#### **INTRODUCTION**

The Alcoa aluminum-lithium alloy 2091-T3 0.063 inch sheets were received October 1988. The 2091-T3 0.063 inch sheet was tested as received by the Air Force and Martin Marietta. However, Northrop and McDonnell Aircraft Company heat treated the alloy to a T8 condition.

#### **TESTING**

Mechanical properties, (tension, compression, bearing, shear, and fracture toughness) fatigue and constant amplitude fatigue crack growth tests were tested according to ASTM standards, unless otherwise specified.

Spectrum tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

TABLE J1

## TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.063" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	RT	LONG	62.5	48.1	19.0	23.0	10.8
MARIETTA, LOUISIANA			61.1	47.0	19.5	23.0	10.6
			61.7	47.5	21.0	23.0	10.1
AIR FORCE	RT	LONG	60.8	47.6	22.4	24.8	
			60.7	47.6	25.1	23.1	
			60.4	47.5	22.9	23.1	
AVERAGE			61.2	47.6	21.7	23.3	10.5
STANDARD DEVIATION			0.8	0.4	1.0	0.3	0.4

TABLE J2

## TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.063" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	45	60.6	40.4	23.4	27.3	
			60.6	40.4	22.9	25.3	
			60.8	41.1	21.8	26.4	
AVERAGE			60.7	40.6	22.7	26.3	
STANDARD DEVIATION			0.1	0.4	0.8	1.0	

TABLE J3

## TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.063" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	60	62.4	41.9	23.6	24.5	
			60.5	39.7	20.4	25.1	
			60.5		22.1	26.2	
AVERAGE			61.1	40.8	22.0	25.3	
STANDARD DEVIATION			1.1	1.6	1.6	0.9	

TABLE J4

## TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.063" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN MARIETTA, LOUISIANA	RT	L TRANS	65.0	43.2	11.0	19.0	10.4
			65.8	44.5	19.0	19.0	10.9
			65.5	42.7	17.0	19.0	8.9
AIR FORCE	RT	L TRANS	63.9	42.7	17.1	20.7	
			63.5	42.1	17.9	21.4	
			64.2	43.7	19.0	21.2	
		AVERAGE	64.7	43.2	16.8	20.1	10.1
		STANDARD DEVIATION	0.9	0.9	3.0	1.2	1.0

R-CURVE FOR 2091-T3, .063 inch SHEET  
(longitudinal)

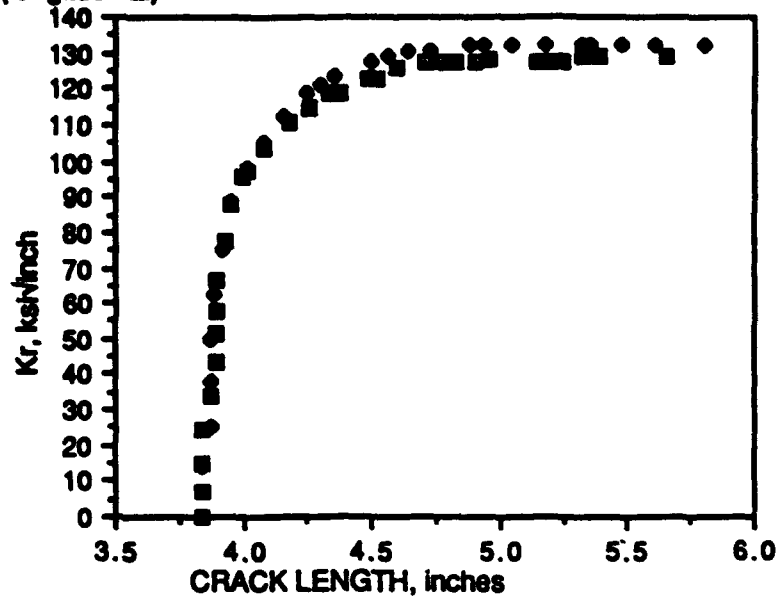


Figure J1. R-Curve Results for 2091-T3 0.063 inch Sheet  
(L-T Orientation).  
Martin Marietta.

R-CURVE FOR 2091-T3, .063 inch SHEET  
(transverse)

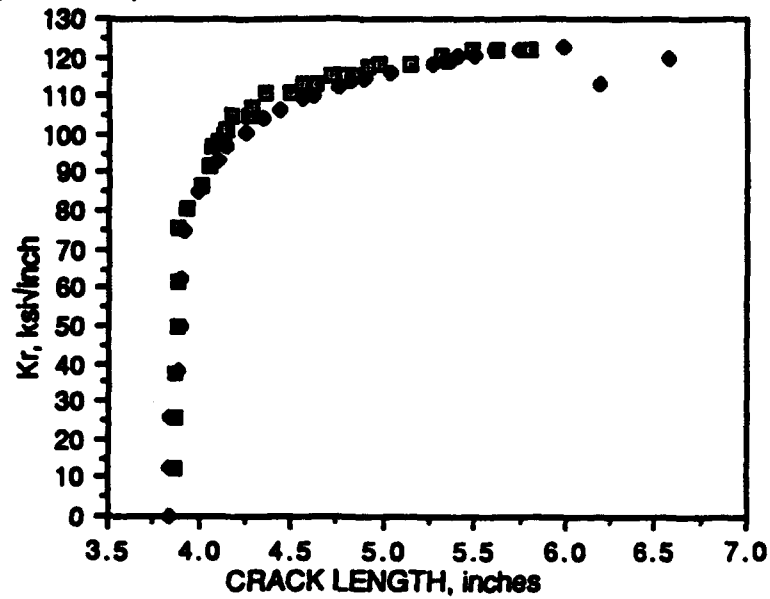


Figure J2. R-Curve Results for 2091-T3 0.063 inch Sheet  
(T-L Orientation).  
Martin Marietta.

R-CURVE FOR 2091, .063 inch Sheet  
(longitudinal)  
(effective crack length adjusted for plastic zone)

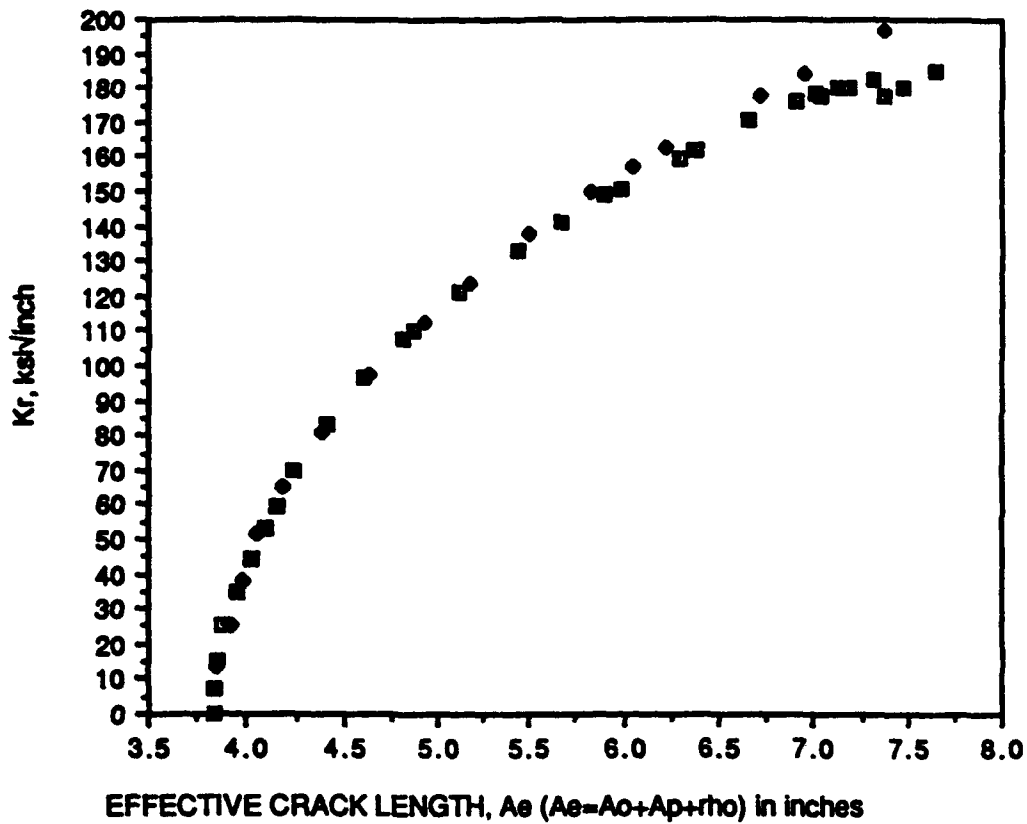


Figure J3. R-Curve Results for 2091-T3 0.063 Inch Sheet,  
with Effective Crack Length Adjusted for  
Plastic Zone (L-T Orientation).  
Martin Marietta.

**R-CURVE FOR 2091-T3, .063 inch SHEET**  
 (transverse)  
 ( effective crack length adjusted for plastic zone)

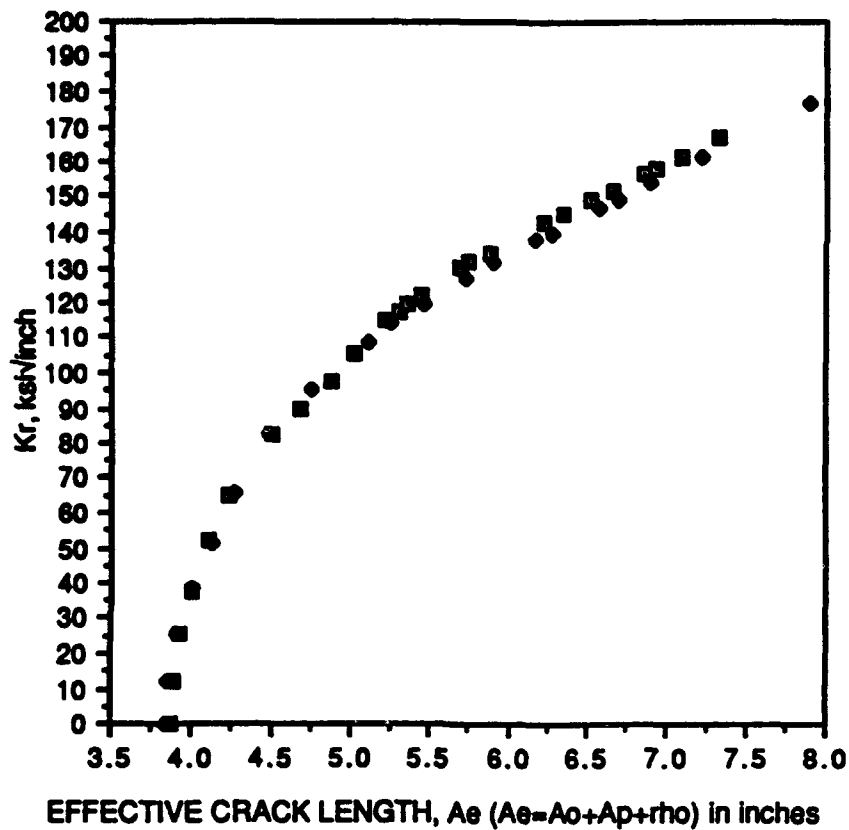


Figure J4. R-Curve Results for 2091-T3 0.063 Inch Sheet, with Effective Crack Length Adjusted for Plastic Zone. (T-L Orientation). Martin Marietta.

TABLE J5  
R-Curve Data Associated with Figures J1 and J3

DATA FOR SPECIMEN NO. 1  
2091-T3 LONGITUDINAL SHEET

Load, kips	Half Crack Length (a), inch	Half Crack Length (a + rho), inch	Corresponding Fracture Toughness, ksi√inch	
			Not Adjusted	Adjusted for Plasticity
0	3.835	3.835	0.0	0.0
3.0	3.835	3.838	7.4	6.9
6.1	3.835	3.851	15.0	15.1
10.1	3.835	3.879	24.9	25.1
13.8	3.870	3.955	34.2	34.6
17.4	3.890	4.027	43.3	44.1
20.8	3.895	4.095	51.8	53.2
23.1	3.900	4.150	57.5	59.5
26.7	3.900	4.241	66.5	69.6
30.9	3.925	4.416	77.3	83.5
34.9	3.950	4.613	87.7	97.0
37.7	3.995	4.813	95.5	107.7
38.3	4.015	4.873	97.3	110.3
40.4	4.080	5.118	103.7	121.3
42.5	4.180	5.437	110.9	133.5
43.4	4.255	5.667	114.6	141.5
44.3	4.330	5.902	118.4	149.3
44.3	4.375	5.985	118.4	151.1
44.7	4.490	6.293	122.4	159.9
44.8	4.515	6.362	122.4	161.8
44.8	4.525	6.384	122.4	162.3
45.2	4.600	6.661	125.9	170.9
44.9	4.710	6.908	127.2	176.5
44.7	4.765	7.013	127.2	178.5
44.3	4.810	7.034	127.2	177.5
44.3	4.830	7.120	127.2	180.2
43.8	4.900	7.186	127.2	180.0
43.6	4.960	7.320	128.3	182.9
42.1	5.140	7.376	127.3	178.0
41.8	5.190	7.473	127.3	179.9
41.7	5.240	7.646	127.3	184.7
41.4	5.325		128.7	
40.9	5.385		128.7	
39.2	5.650		128.7	
35.6	6.040		123.2	

Thickness = .063 inches  
Yield Strength = 47.5 ksi  
Specimen Width = 23.88 inches

**TABLE J6**  
**R-Curve Data Associated with Figures J1 and J3**

**DATA FOR SPECIMEN NO. 2**  
**2091-T3 LONGITUDINAL SHEET**

Load, kips	Half Crack Length (a), inch	Half Crack Length (a + rho), inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not Adjusted	Adjusted for Plasticity
0	3.835	3.835	0.0	0.0
5.7	3.835	3.847	14.1	13.2
10.2	3.875	3.921	25.3	25.5
15.2	3.875	3.978	37.8	38.3
20.1	3.875	4.060	49.9	51.2
25.2	3.885	4.185	62.7	65.2
30.1	3.920	4.382	75.3	80.9
35.1	3.955	4.630	88.3	97.8
38.7	4.020	4.921	98.4	113.0
41.0	4.085	5.172	105.4	124.1
43.3	4.160	5.501	112.7	137.9
44.9	4.245	5.825	118.4	149.7
45.5	4.305	6.042	121.1	156.9
46.0	4.355	6.225	123.4	162.8
46.5	4.495	6.723	127.5	177.7
46.5	4.560	6.951	128.8	184.1
46.5	4.635	7.376	130.3	197.1
46.0	4.730		130.3	
45.3	4.885		131.9	
44.9	4.940		131.9	
44.2	5.045		131.9	
43.4	5.175		131.9	
42.3	5.325		131.9	
42.5	5.350		131.9	
41.6	5.470		131.9	
40.4	5.610		131.9	
39.3	5.800		131.9	

Thickness = .063 inches  
Yield Strength = 47.5 ksi  
Specimen Width = 23.87 inches

**TABLE J7**  
**R-Curve Data Associated with Figures J2 and J4**

**DATA FOR SPECIMEN NO. 3**

**2091-T3 TRANSVERSE SHEET**

Load, kips	Half Crack Length (a), inch	Half Crack Length (a + rho), inch	Corresponding Fracture Toughness, ksi√inch	
			Not Adjusted	Adjusted for Plasticity
0	3.875	3.875	0.0	0.0
5.1	3.875	3.887	12.7	11.8
10.3	3.875	3.931	25.6	25.8
15.0	3.880	4.001	37.3	37.9
20.2	3.880	4.105	50.2	51.8
24.8	3.880	4.230	61.6	64.5
30.1	3.925	4.494	75.4	82.3
31.9	4.000	4.673	80.9	89.5
34.0	4.055	4.861	87.0	97.9
35.8	4.070	5.015	91.8	106.0
37.7	4.105	5.214	97.2	114.8
38.1	4.135	5.293	98.7	117.4
38.6	4.145	5.354	100.2	119.9
39.0	4.175	5.439	101.7	122.6
39.8	4.260	5.684	105.2	130.1
39.9	4.290	5.748	105.2	131.7
40.0	4.360	5.883	107.4	134.6
40.4	4.500	6.226	110.9	143.2
40.4	4.555	6.338	110.9	145.6
40.4	4.640	6.519	113.3	149.5
40.2	4.710	6.660	113.3	152.3
40.2	4.790	6.856	115.4	156.7
40.1	4.830	6.934	115.4	158.2
39.8	4.910	7.099	115.4	161.3
39.8	4.975	7.318	117.5	167.4
39.2	5.140		118.6	
38.5	5.315		118.6	
37.7	5.485		120.1	
37.5	5.625		122.0	
36.5	5.810		122.0	

Thickness = .063 inches  
Yield Strength = 43.5 ksi  
Specimen Width = 23.87 inches

TABLE J8

## R-CURVE DATA ASSOCIATED WITH FIGURES J2 AND J4

## DATA FOR SPECIMEN NO. 4

## 2091-T3 TRANSVERSE SHEET

Load, kips	Half Crack Length (a), inch	Half Crack Length (a + rho), inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not Adjusted	Adjusted for Plasticity
0.0	3.845	3.845	0.0	0.0
5.1	3.845	3.857	12.6	11.8
10.4	3.845	3.901	25.7	25.9
15.3	3.880	4.006	38.0	38.7
20.0	3.895	4.116	49.8	51.3
25.1	3.895	4.256	62.5	65.5
30.1	3.915	4.481	75.2	82.1
33.7	3.985	4.751	85.2	95.5
36.2	4.105	5.092	93.3	108.4
37.4	4.145	5.246	97.0	114.4
38.1	4.245	5.459	100.4	120.1
38.8	4.350	5.717	104.0	127.5
39.2	4.430	5.900	106.4	132.2
39.4	4.565	6.170	109.2	138.1
39.4	4.625	6.282	110.2	140.4
39.4	4.755	6.571	112.4	146.9
39.4	4.815	6.701	113.5	149.8
39.3	4.900	6.905	114.6	154.4
39.1	5.030	7.226	116.3	161.6
38.3	5.260	7.896	117.9	177.0
38.3	5.320		119.0	
38.3	5.350		119.0	
38.2	5.400		120.1	
37.7	5.495		120.1	
37.6	5.605		121.9	
36.9	5.735		121.9	
35.8	5.990		122.9	
31.9	6.185		112.8	
31.9	6.575		119.7	

Thickness = .063 inches  
Yield Strength = 43.5 ksi  
Specimen Width = 23.88 inches

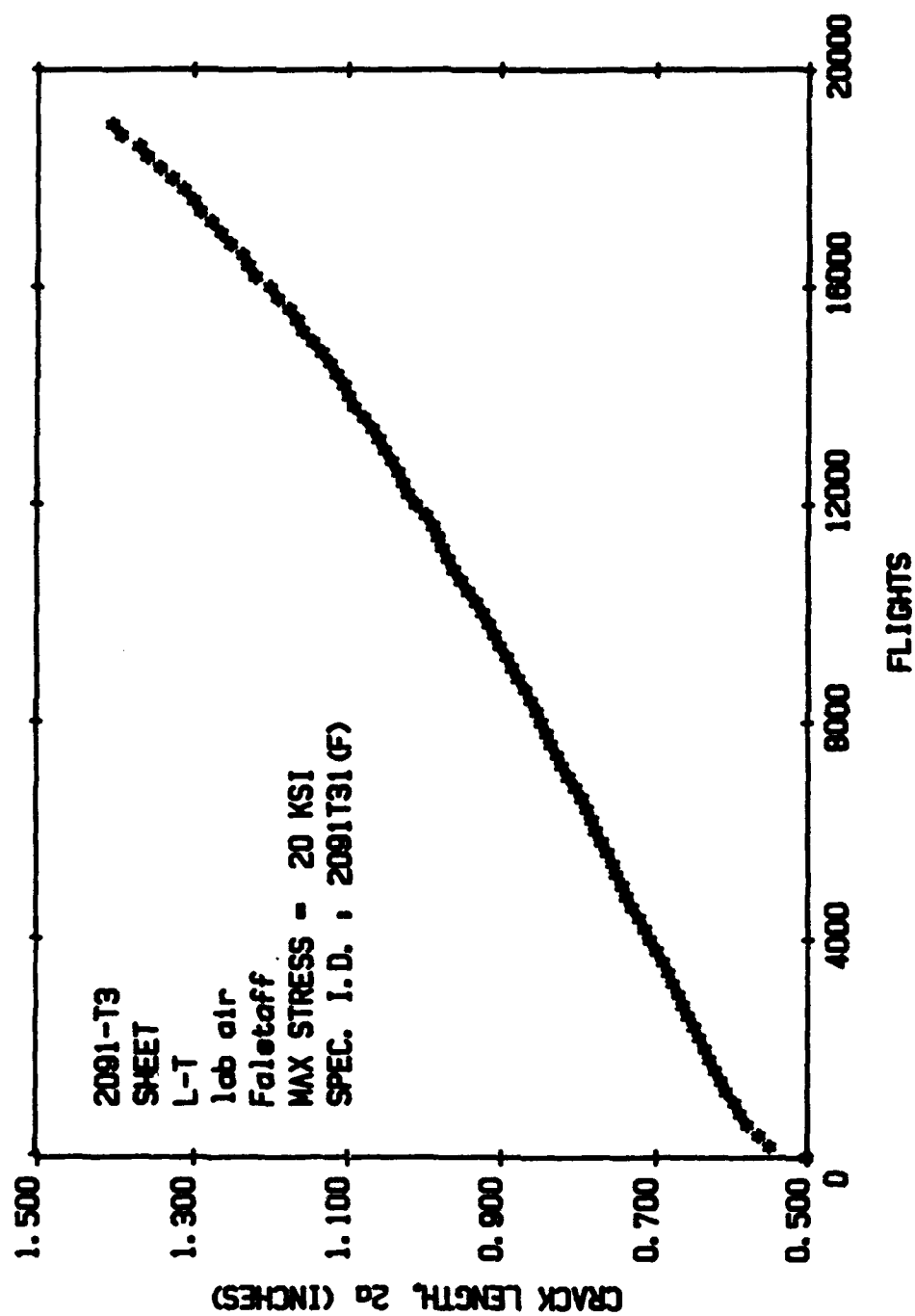


FIGURE J5. FALSTAFF SPECTRUM  
CRACK LENGTH VS FLIGHTS DATA FOR 2091-T3  
0.063 INCH SHEET,  
AIR FORCE.

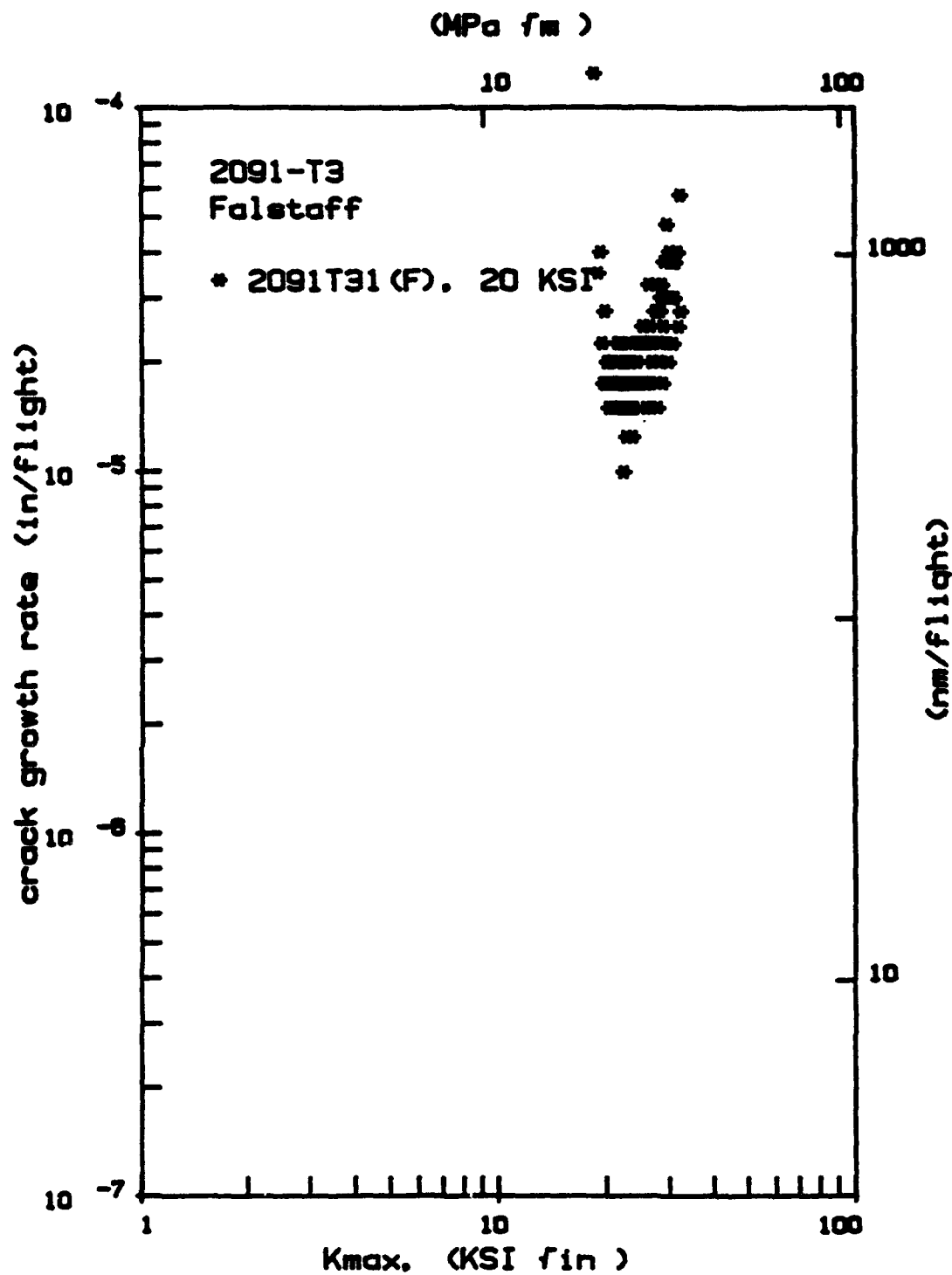


Figure J6. FALSTAFF Spectrum Crack Growth Rate  
 vs Kmax Data for 2091-T3  
 0.063 Inch Sheet.  
 Air Force

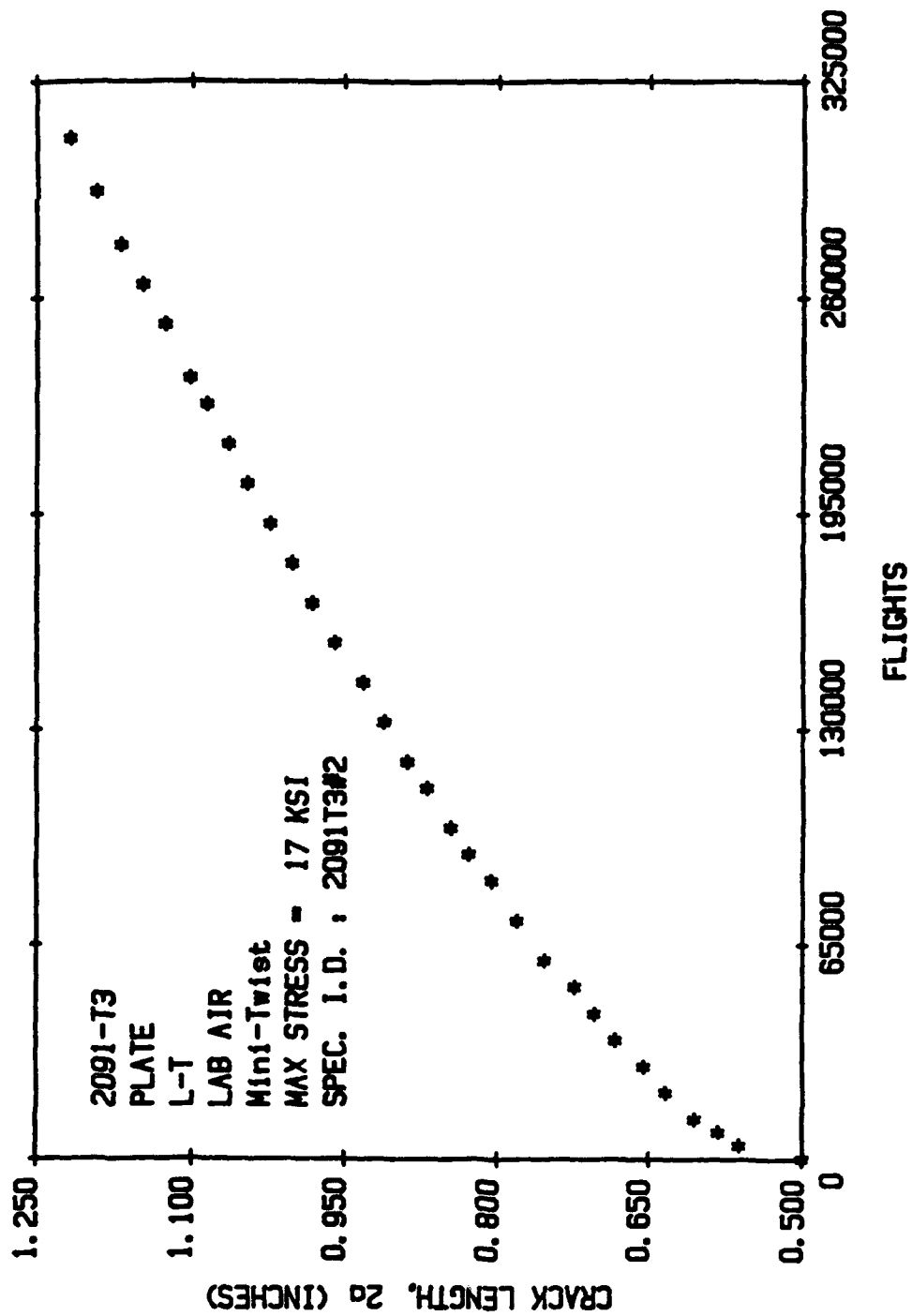


Figure J7. Mini-TWIST Spectrum Crack Length vs Flights Data for  
for 2091-T3 0.063 Inch Sheet.  
Air Force

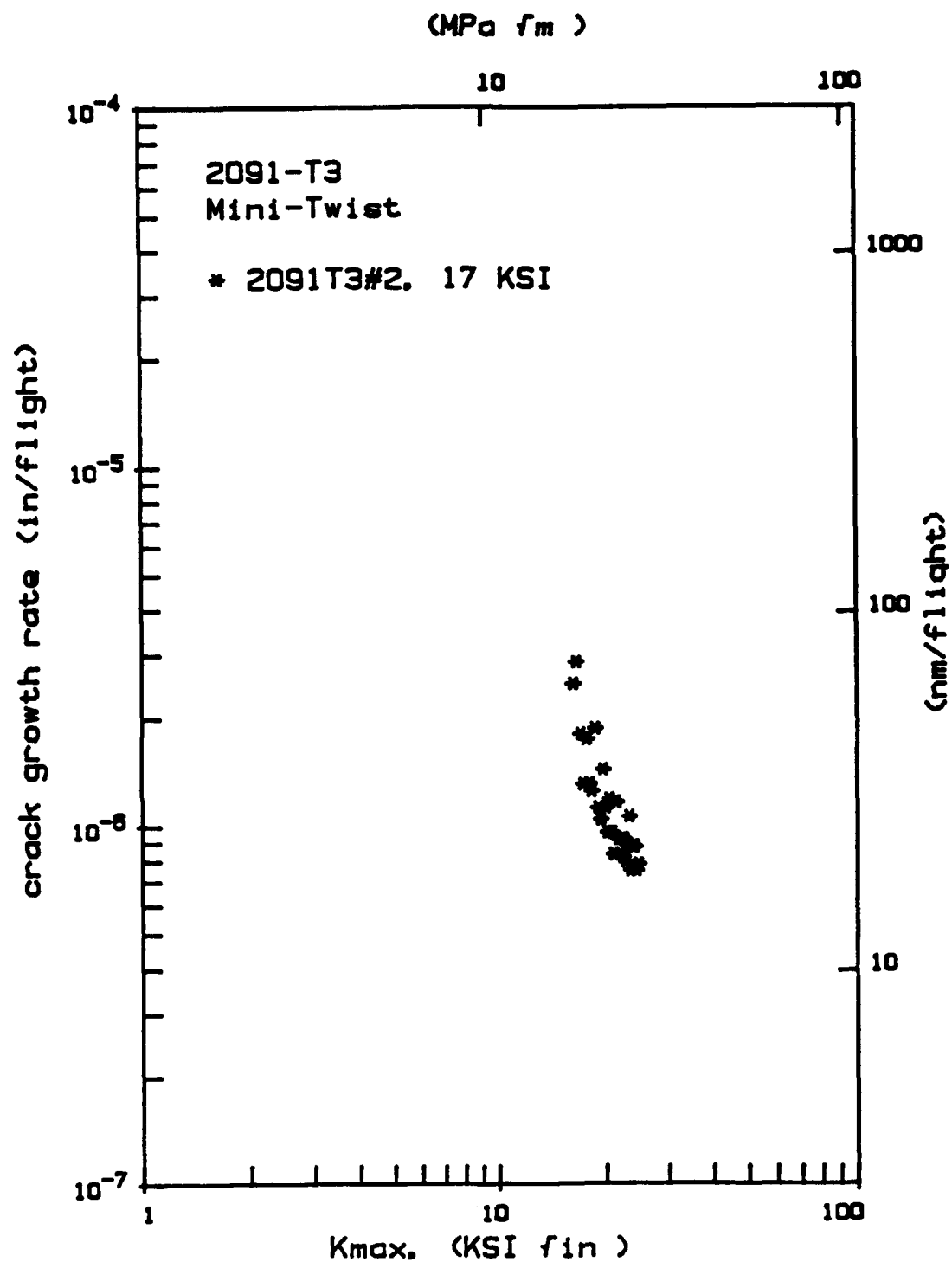


Figure J8. Mini-TWIST Spectrum Crack Growth Rate vs  
 Kmax Data for 2091-T3  
 0.063 Inch Sheet, Air Force

**TABLE J9**  
**TENSILE RESULTS FOR ALCOA**  
**2091-T8 SHEET (0.063" X 48" X 48")**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCAIR	RT	LONG	62.5	50.0	22.0		5.5
			62.5	49.4	21.0		5.4
			61.5	49.2	20.0		5.9
NORTHROP	RT	LONG	65.2	53.2	21.9		11.2
			64.9	52.9	19.0		11.2
			64.9	53.1	21.9		11.2
			64.7	52.9	21.9		11.3
AVERAGE			63.7	51.5	21.1		8.8
STANDARD DEVIATION			1.5	1.9	0.6		3.0

**TABLE J10**  
**TENSILE RESULTS FOR ALCOA**  
**2091-T8 SHEET (0.063" X 48" X 48")**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCAIR	RT	45 DEG	62.0	38.0	24.0		6.0
			62.0	38.5	25.0		5.9
			62.5	38.0	22.0		6.7
NORTHROP	RT	45 DEG	64.3	43.9	16.9		11.0
			63.4	43.8	14.1		11.0
			64.1	43.9	17.2		11.2
			63.8	43.1	16.7		11.0
AVERAGE			63.2	41.3	19.4		9.0
STANDARD DEVIATION			1.0	3.0	4.2		2.6

TABLE J11

## TENSILE RESULTS FOR ALCOA

2091-T8 SHEET (0.063" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCAIR	RT	L TRANS	64.5	40.9	18.0		5.6
			65.0	43.6	16.0		5.9
			66.0	42.3	21.0		5.5
NORTHROP	RT	L TRANS	67.9	47.7	20.8		11.3
			68.2	47.4	18.2		11.3
			67.5	47.7	16.9		11.2
			68.3	47.2	18.7		11.1
		AVERAGE	65.2	42.3	18.3		5.7
		STANDARD DEVIATION	0.8	1.4	2.5		0.2

TABLE J12

## COMPRESSION RESULTS FOR ALCOA

2091-T8 SHEET (0.063" X 48" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MCAIR	RT	LONG		12.5 11.5
NORTHROP	RT	LONG	41.7 42.2 41.7	11.5 11.2 12.1
		AVERAGE	41.9	11.8
		STANDARD DEVIATION	0.3	0.5

TABLE J13

## COMPRESSION RESULTS FOR ALCOA

2091-T8 SHEET (0.063" X 48" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MCAIR	RT	45 DEG		12.1 12.2 11.7
		AVERAGE		12.0
		STANDARD DEVIATION		0.3

TABLE J14

COMPRESSION RESULTS FOR ALCOA

2091-T8 SHEET (0.063" X 48" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MCAIR	RT	L TRANS		12.6 12.6 12.5
NORTHROP	RT	L TRANS	48.4 48.8 48.9	12.1 11.9 12.0
		AVERAGE	48.7	12.3
		STANDARD DEVIATION	0.3	0.3

**TABLE J15**  
**SLOTTED SHEAR RESULTS FOR ALCOA**  
**2091-T8 SHEET (0.063" X 48" X 48")**

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
MCAIR	LONG	44.8
		46.8
NORTHROP	LONG	43.9
		43.8
		43.7
	AVERAGE	44.6
	STANDARD DEVIATION	1.3

**TABLE J16**  
**SLOTTED SHEAR RESULTS FOR ALCOA**  
**2091-T8 SHEET (0.063" X 48" X 48")**

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
NORTHROP	L TRANS	44.7
		45.0
		44.6
	AVERAGE	44.8
	STANDARD DEVIATION	0.2

**TABLE J17**  
**BEARING RESULTS FOR ALCOA**  
**2091-T8 SHEET (0.063" X 48" X 48")**

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
MCAIR	LONG	1.5		96.1		
				98.9		83.5
				99.2		83.9
NORTHROP	LONG	1.5		101.6		71.1
				100.7		69.7
				101.7		72.2
AVERAGE				99.7		76.1
STANDARD DEVIATION				2.1		7.0

**TABLE J18**  
**BEARING RESULTS FOR ALCOA**  
**2091-T8 SHEET (0.063" X 48" X 48")**

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
MCAIR	L TRANS	1.5		98.2		85.7
				97.4		84.0
				97.5		85.1
NORTHROP	L TRANS	1.5		104.4		76.9
				103.7		73.9
				104.0		75.4
AVERAGE				100.9		80.2
STANDARD DEVIATION				3.5		5.3

TABLE J19

## BEARING RESULTS FOR ALCOA

2091-T8 SHEET (0.063" X 48" X 48")

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
MCAIR	LONG	2.0		128.6		107.0
				130.3		108.4
				127.1		107.0
NORTHROP	LONG	2.0		127.3		72.8
				129.9		76.0
				130.2		74.7
AVERAGE				128.9		91.0
STANDARD DEVIATION				1.5		18.1

TABLE J20

## BEARING RESULTS FOR ALCOA

2091-T8 SHEET (0.063" X 48" X 48")

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
MCAIR	L TRANS	2.0		131.2		110.7
				130.6		109.5
				128.3		107.0
NORTHROP	L TRANS	2.0		130.4		85.2
				129.7		85.0
				129.0		88.2
AVERAGE				129.9		97.6
STANDARD DEVIATION				1.1		12.7

**TABLE J21**

**R-CURVE FRACTURE TOUGHNESS  
RESULTS FOR 2091-T8X SHEET  
(0.063" X 48" X 48")  
Northrop**

<b>Specimen ID</b>	<b>Orientation</b>	<b>Kc</b>
<b>VIRLI</b>	<b>L-T</b>	<b>130.0</b>

TABLE J22

## R-CURVE FRACTURE TOUGHNESS RESULTS

For 2091-T8 Sheet (0.063" x 48" x 48")

MCDONNELL AIRCRAFT CO

SPECIMEN IDENTIFICATION: LT1  
 MATERIAL DESCRIPTION: 2091 AL-LI SHEET  
 SPECIMEN TYPE: C(T) (COMPACT SPECIMEN)  
 SPECIMEN ORIENTATION: L-T  
 YIELD STRENGTH: 49.5 KSI  
 SPECIMEN THICKNESS: 0.063 IN  
 SPECIMEN WIDTH: 3.999 IN

SPECIMEN IS INVALID PER ASTM E561-86, PARA. 7.5

APPLIED LOAD (lbs)	PHYSICAL CRACK LENGTH (in)	Kr (UNCORRECTED) (psi √in)	EFFECTIVE CRACK LENGTH (in)	Kr (CORRECTED) (psi √in)
800	1.485	42,884	1.629	47,141
975	1.500	52,765	1.753	62,495
1,025	1.507	55,716	1.810	68,349
1,100	1.516	60,171	1.935	80,342
1,150	1.523	63,194	***	***
1,175	1.529	64,829	***	***
1,200	1.534	66,420	***	***
1,225	1.545	68,270	***	***
1,250	1.555	70,121	***	***
1,275	FAILURE	---	---	---

\*\*\* Indicates that the equation for Kr (Corrected) did not converge to a solution.

TABLE J23

## R-CURVE FRACTURE TOUGHNESS RESULTS

For 2091-T8 Sheet (0.063" x 48" x 48")

MCDONNELL AIRCRAFT CO

SPECIMEN IDENTIFICATION: LT2  
 MATERIAL DESCRIPTION: 2091 AL-LI SHEET  
 SPECIMEN TYPE: C(T) (COMPACT SPECIMEN)  
 SPECIMEN ORIENTATION: L-T  
 YIELD STRENGTH: 49.5 KSI  
 SPECIMEN THICKNESS: 0.064 IN  
 SPECIMEN WIDTH: 4.002 IN

SPECIMEN IS INVALID PER ASTM E561-86, PARA. 7.5

APPLIED LOAD (lbs)	PHYSICAL CRACK LENGTH (in)	Kr (UNCORRECTED) (psi $\sqrt{in}$ )	EFFECTIVE CRACK LENGTH (in)	Kr (CORRECTED) (psi $\sqrt{in}$ )
975	1.501	51,927	1.743	60,983
1,000	1.515	53,727	1.783	64,343
1,050	1.523	56,711	1.847	70,665
1,110	1.526	60,073	1.943	80,115
1,160	1.530	62,951	***	***
1,190	1.534	64,769	***	***
1,220	1.540	66,640	***	***
1,235	1.543	67,574	***	***
1,270	1.549	69,785	***	***
1,285	1.570	71,568	***	***
1,305	1.576	72,983	***	***
1,315	1.585	73,989	***	***
1,325	1.592	74,876	***	***
1,335	1.598	75,731	***	***
1,340	1.605	76,397	***	***
1,345	FAILURE	---	---	---

\*\*\* Indicates that the equation for Kr (Corrected) did not converge to a solution.

TABLE J24

## R-CURVE FRACTURE TOUGHNESS RESULTS

For 2091-T8 Sheet (0.063" x 48" x 48")

MCDONNELL AIRCRAFT CO

SPECIMEN IDENTIFICATION: TL1  
 MATERIAL DESCRIPTION: 2091 AL-LI SHEET  
 SPECIMEN TYPE: C(T) (COMPACT SPECIMEN)  
 SPECIMEN ORIENTATION: T-L  
 YIELD STRENGTH: 42.3 KSI  
 SPECIMEN THICKNESS: 0.064 IN  
 SPECIMEN WIDTH: 3.998 IN

SPECIMEN IS INVALID PER ASTM E561-86, PARA. 7.5

APPLIED LOAD (lbs)	PHYSICAL CRACK LENGTH (in)	Kr (UNCORRECTED) (psi /in)	EFFECTIVE CRACK LENGTH (in)	Kr (CORRECTED) (psi /in)
800	1.495	42,504	1.708	48,955
825	1.499	43,946	1.734	51,378
1,025	1.503	54,749	***	***
1,050	1.509	56,296	***	***
1,085	1.513	58,335	***	***
1,095	1.518	59,045	***	***
1,135	1.524	61,462	***	***
1,165	1.535	63,532	***	***
1,175	1.544	64,468	***	***
1,190	1.544	65,291	***	***
1,215	1.549	66,881	***	***
1,230	1.557	68,045	***	***
1,240	1.562	68,819	***	***
1,250	1.583	70,357	***	***
1,270	1.587	71,638	***	***
1,280	1.594	72,565	***	***
1,290	1.612	73,989	***	***
1,295	1.616	74,493	***	***
1,305	FAILURE	---	---	---

\*\*\* Indicates that the equation for Kr (Corrected) did not converge to a solution.

TABLE J25

## R-CURVE FRACTURE TOUGHNESS RESULTS

For 2091-T8 Sheet (0.063" x 48" x 48")

MCDONNELL AIRCRAFT CO

SPECIMEN IDENTIFICATION: TL2  
 MATERIAL DESCRIPTION: 2091 AL-LI SHEET  
 SPECIMEN TYPE: C(T) (COMPACT SPECIMEN)  
 SPECIMEN ORIENTATION: T-L  
 YIELD STRENGTH: 42.3 KSI  
 SPECIMEN THICKNESS: 0.061 IN  
 SPECIMEN WIDTH: 3.999 IN

SPECIMEN IS INVALID PER ASTM E561-86, PARA. 7.5

APPLIED LOAD (lbs)	PHYSICAL CRACK LENGTH (in)	Kr (UNCORRECTED) (psi /in)	EFFECTIVE CRACK LENGTH (in)	Kr (CORRECTED) (psi /in)
950	1.507	53,350	2.062	79,002
975	1.511	54,882	***	***
1,075	1.517	60,775	***	***
1,120	1.522	63,517	***	***
1,130	1.526	64,248	***	***
1,180	1.531	67,305	***	***
1,240	1.541	71,181	***	***
1,255	1.544	72,179	***	***
1,265	1.550	73,059	***	***
1,280	1.569	74,867	***	***
1,285	1.576	75,466	***	***
1,295	FAILURE	---	---	---

\*\*\* Indicates that the equation for Kr (Corrected) did not converge to a solution.

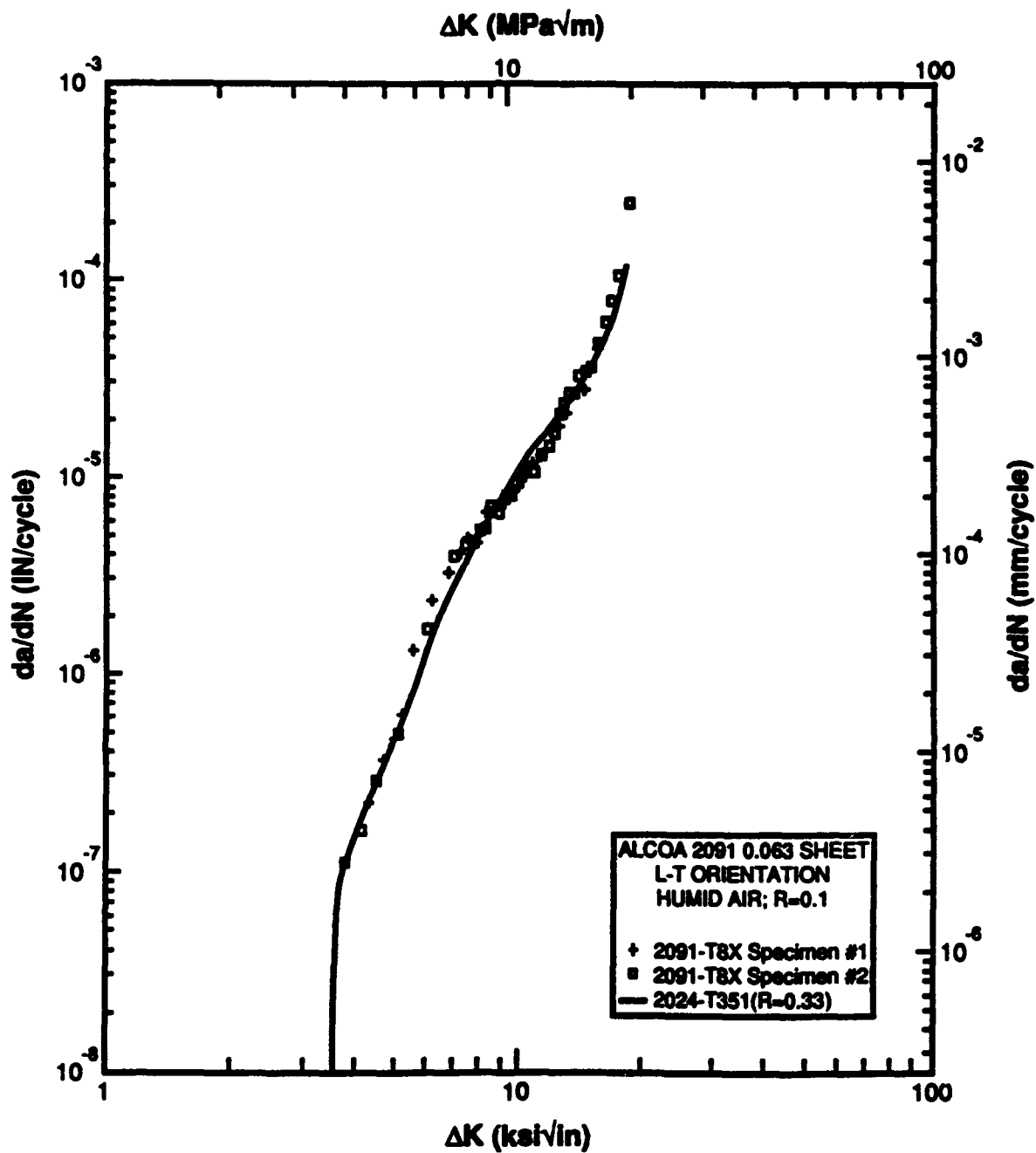


FIGURE J9. FATIGUE CRACK GROWTH RATE DATA for 2091-T8X 0.063 Inch Sheet Relative to 2024-T351 (L-T Orientation). Northrop.



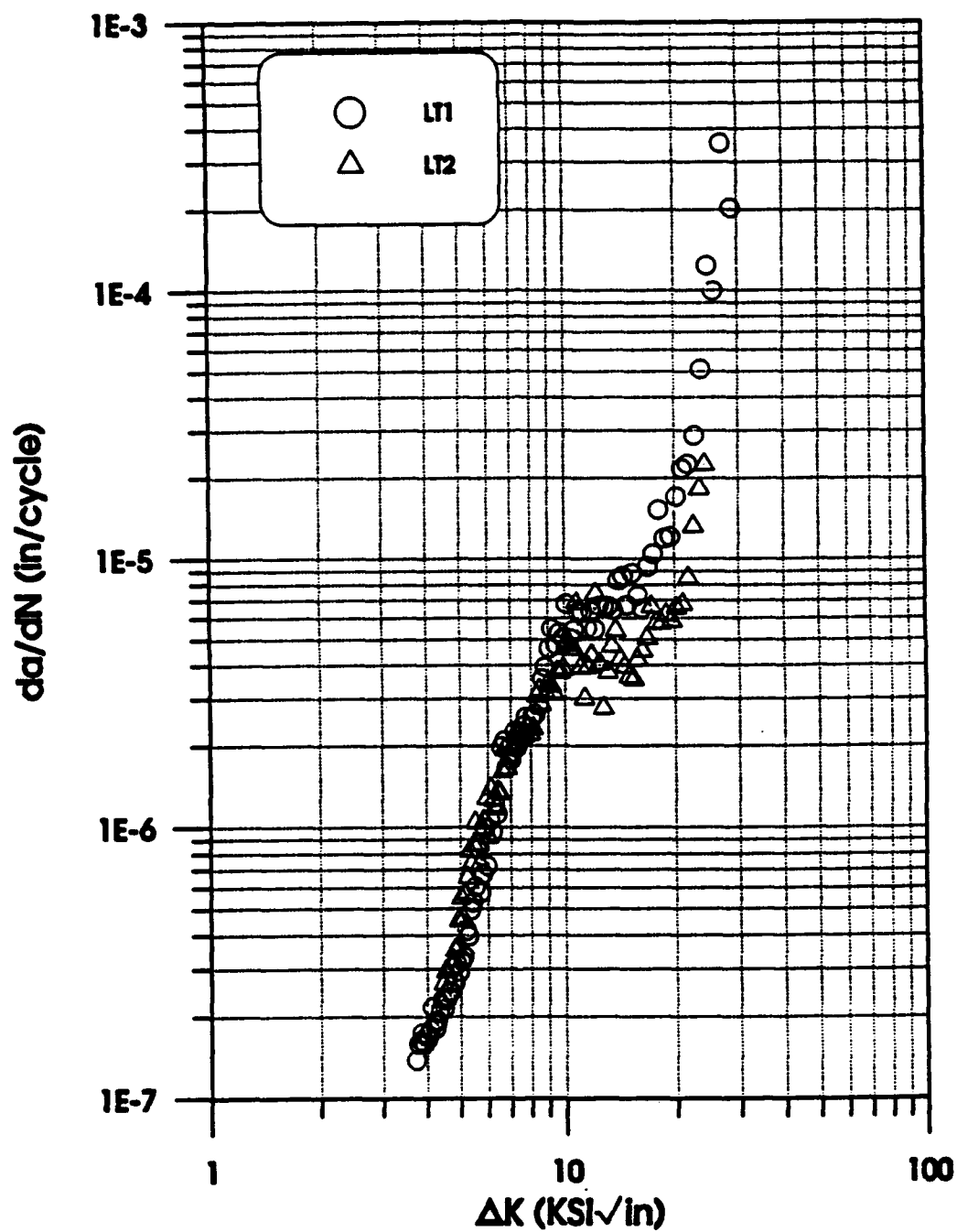


Figure J11 Figure Crack Growth Rate Data for 2091-T8 0.063 Inch Sheet. (L-T Orientation, R=0.33, Lab Air and 750F). McDonnell Aircraft Company.

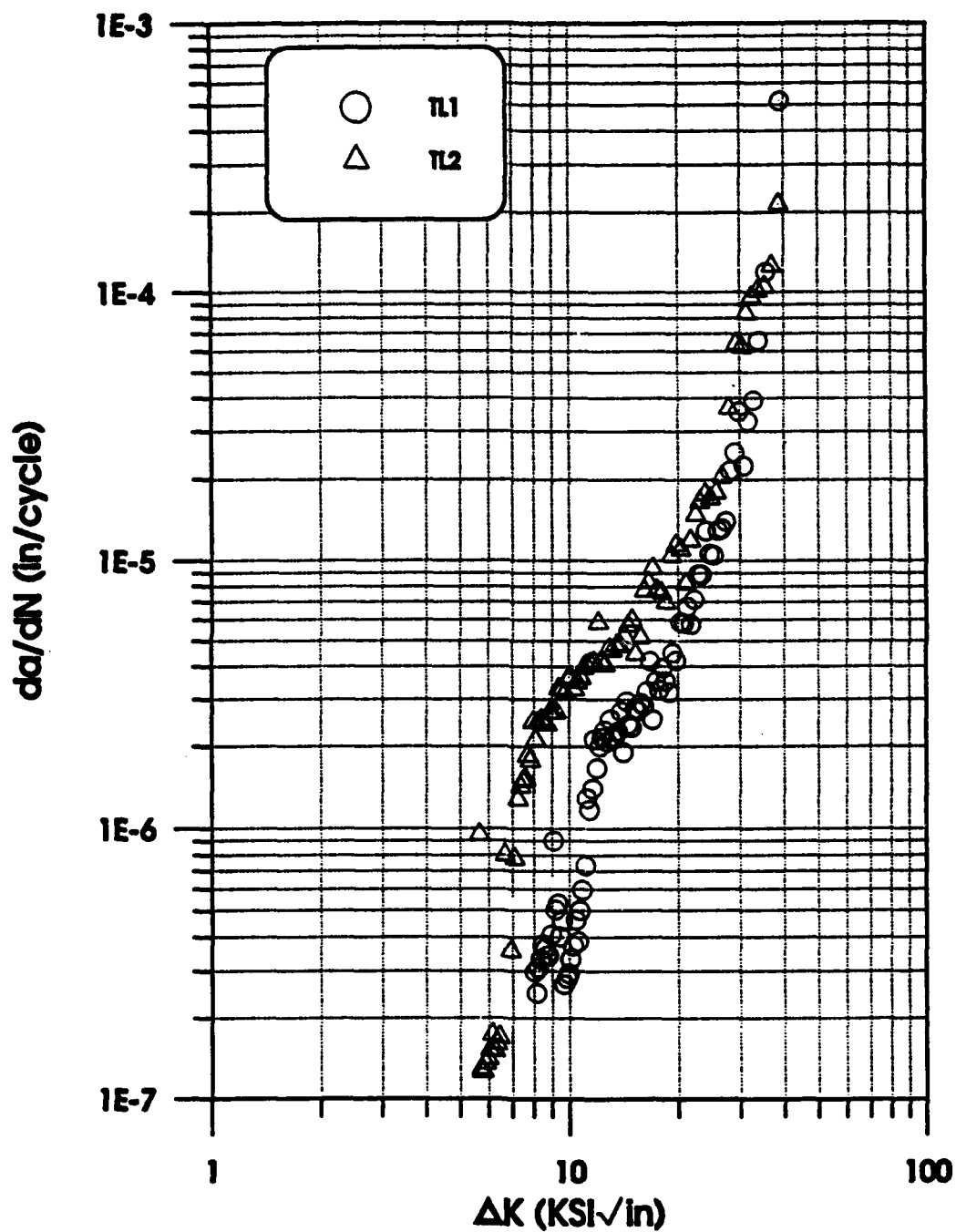


Figure J12 Fatigue Crack Growth Rate Data for 2091-T8 0.063 Inch Sheet (T-L Orientation, Lab Air, 75°F, and TL1 R=0.02 and TL2 R=0.10). McDonnell Aircraft Company

## **APPENDIX K**

### **2091-T3 AND 2091-T8 0.144 INCH SHEET**

#### **INTRODUCTION**

The Alcoa aluminum-lithium alloy 2091-T3 0.144 inch sheets were received March 1988. The 2091-T3 0.144 inch sheets were tested as received by the Air Force, Martin Marietta and McDonnell Douglas Astronautics. However, General Dynamics aged their material at 16 and 32 hours at 335°F and Northrop heat treated their material to a T8X temper.

#### **TESTING**

Mechanical properties, (tension, compression, bearing, shear, and fracture toughness) fatigue and constant amplitude fatigue crack growth tests were tested according to ASTM standards, unless otherwise specified.

Spectrum tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

TABLE K1

## TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCDONNELL	RT	LONG	59.4	49.0	20.0		11.4
DOUGLAS			60.1	49.2	20.0		11.6
ASTRO., CA			59.9	49.5	20.0		11.5
			59.9	49.6	20.0		11.5
			58.9	49.5	22.0		11.5
MARTIN							
MARIETTA, LA	RT	LONG	60.6	50.0	17.0	12.7	11.4
			59.9	49.6	17.0	15.5	11.1
			59.9	49.6	17.0	19.7	11.4
AIR FORCE	RT	LONG	61.4	51.1	14.3	14.7	
			61.4	50.9	17.9	20.5	
			61.4	51.3	17.2	19.7	
AVERAGE			60.3	49.9	18.4	17.1	11.4
STANDARD DEVIATION			0.8	0.8	2.2	3.2	0.1

TABLE K2

## TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	30	62.4	45.0	20.0	25.6	
			62.1	44.0	19.1	25.4	
			62.2	43.2	18.9	25.5	
AVERAGE			62.2	44.1	19.3	25.5	
STANDARD DEVIATION			0.2	0.9	0.6	0.1	

TABLE K3

## TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
-----							
AIR FORCE	RT	45	61.4	42.0	23.3	28.3	
			61.6	42.7	24.4	28.2	
			61.5	42.7	23.9	29.3	
AVERAGE			61.5	42.5	23.9	28.6	
STANDARD DEVIATION			0.1	0.4	0.6	0.6	

TABLE K4

## TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
-----							
AIR FORCE	RT	60	61.2	40.9	24.0	29.0	
			61.0	43.3	21.5	27.8	
			60.3	41.5	22.8	31.1	
AVERAGE			60.8	41.9	22.8	29.3	
STANDARD DEVIATION			0.5	1.2	1.3	1.7	

TABLE K5

## TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCDONNELL	RT	L TRANS	64.3				12.0
DOUGLAS			65.3	46.6	14.0		11.6
ASTRO., CA			65.2	46.6	14.0		11.6
			64.3	46.4	12.5		11.5
			64.6	46.7	12.5		11.6
MARTIN	RT	L TRANS	64.7	46.2	12.0	12.7	11.1
MARIETTA, LA			65.1	45.8	13.0	11.3	11.4
			64.7	45.6	13.0	11.3	11.3
AIR FORCE	RT	L TRANS	66.0	47.3	16.4	16.2	
			66.4	47.4	17.5	17.3	
			66.0	47.5	15.7	18.8	
		AVERAGE	65.1	46.6	14.1	14.6	11.5
		STANDARD DEVIATION	0.7	0.6	1.9	3.3	0.3

TABLE K6

## TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCDONNELL	-320 F	LONG	75.3	57.6	16.0		12.4
DOUGLAS			76.2	58.1	16.5		12.5
ASTRO., CA			75.1	57.4	17.0		12.5
			75.0	58.0	17.0		12.5
		AVERAGE	75.4	57.8	16.6		12.5
		STANDARD DEVIATION	0.5	0.3	0.5		0.1

TABLE K7

## TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCDONNELL	-320 F	L TRANS	81.6	53.9	16.5		12.7
DOUGLAS			82.2	54.2	14.5		12.7
ASTRO., CA			81.5	55.1	14.5		12.7
			80.6	55.1	13.0		12.5
		AVERAGE	81.5	54.6	14.6		12.7
		STANDARD DEVIATION	0.7	0.6	1.4		0.1

TABLE K8

## COMPRESSION RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MCDONNELL	RT	LONG	41.1	11.5
DOUGLAS				11.5
ASTRO., CA			40.7	11.4
AVERAGE			40.9	11.5
STANDARD DEVIATION			0.3	0.1

TABLE K9

## COMPRESSION RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MCDONNELL	RT	L TRANS	49.0	11.3
DOUGLAS			48.6	11.5
ASTRO., CA			49.8	11.5
AVERAGE			49.1	11.4
STANDARD DEVIATION			0.6	0.1

TABLE K10

COMPRESSION RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MCDONNELL	-320 F	LONG	46.8	12.7
DOUGLAS				12.5
ASTRO., CA			46.4	12.4
AVERAGE			46.6	12.5
STANDARD DEVIATION			0.3	0.2

TABLE K11

COMPRESSION RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MCDONNELL	-320 F	L TRANS	56.8	12.8
DOUGLAS			55.1	12.8
ASTRO., CA			58.8	12.5
AVERAGE			56.9	12.7
STANDARD DEVIATION			1.9	0.2

**TABLE K12**  
**BEARING RESULTS FOR ALCOA**  
**2091-T3 SHEET (0.144" X 48" X 48")**

COMPANY	ORIENTATION	e/D	BEARING		
			ULT. STR. (KSI)	YIELD STR. (KSI)	
MCDONNELL	LONG	1.5	95.6		
DOUGLAS			95.9	75.3	
ASTRO., CA			95.3	75.8	
			95.2	74.3	
			95.1	72.9	
			AVERAGE		95.4
STANDARD DEVIATION			0.3	1.3	

**TABLE K13**  
**BEARING RESULTS FOR ALCOA**  
**2091-T3 SHEET (0.144" X 48" X 48")**

COMPANY	ORIENTATION	e/D	BEARING			
			ULT. STR. (KSI)	YIELD STR. (KSI)		
MCDONNELL	L TRANS	1.5	98.1	75.3		
DOUGLAS			98.2	74.2		
ASTRO., CA			98.5	78.6		
			96.5	74.6		
			98.1			
			AVERAGE	97.9	75.7	
			STANDARD DEVIATION	0.8	2.0	

**TABLE K14**  
**BEARING RESULTS FOR ALCOA**  
**2091-T3 SHEET (0.144" X 48" X 48")**

COMPANY	ORIENTATION	e/D	BEARING		BEARING		
			ULT.	STR.	YIELD STR.		
			(KSI)		(KSI)		
MCDONNELL	LONG	2.0	119.0		86.2		
DOUGLAS			119.0				
ASTRO., CA			120.0		86.6		
			120.0				
			120.0		85.3		
AVERAGE			119.6		86.0		
STANDARD DEVIATION			0.5		0.7		

**TABLE K15**  
**BEARING RESULTS FOR ALCOA**  
**2091-T3 SHEET (0.144" X 48" X 48")**

COMPANY	ORIENTATION	e/D	BEARING		BEARING		
			ULT.	STR.	YIELD STR.		
			(KSI)		(KSI)		
MCDONNELL	L TRANS	2.0	122.0		89.2		
DOUGLAS			122.0		90.7		
ASTRO., CA			122.0				
			123.0		88.7		
			121.0		87.9		
AVERAGE			122.0		89.1		
STANDARD DEVIATION			0.7		1.2		

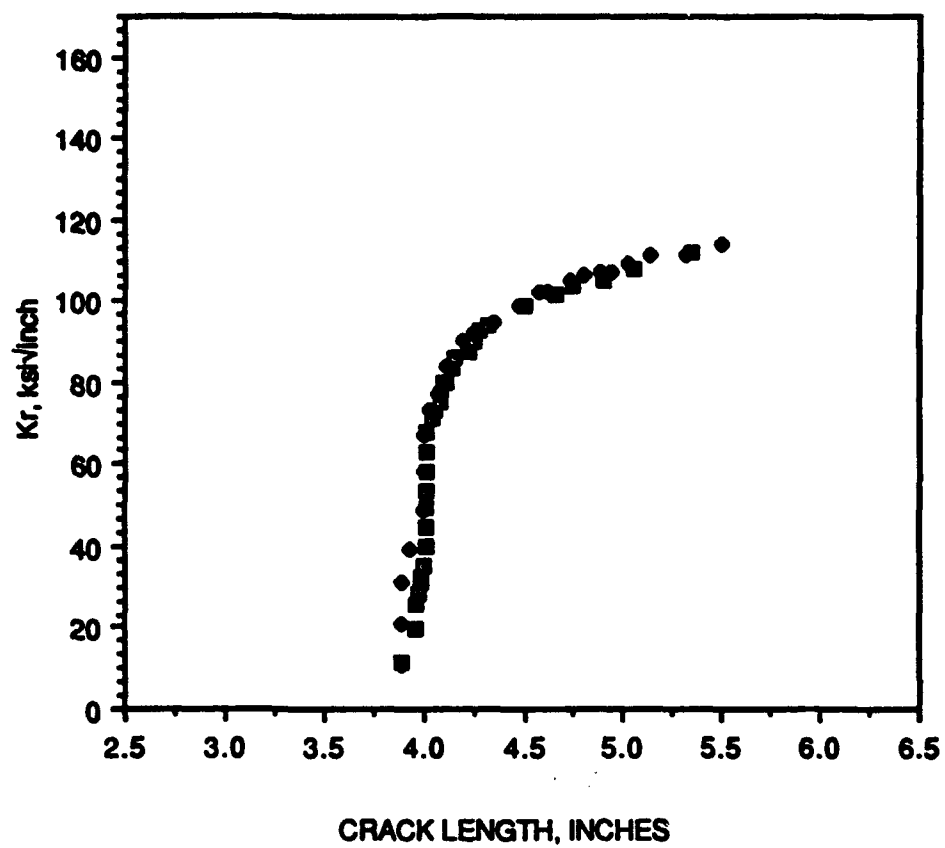


Figure K1. R-Curve Results for 2091-T3  
0.144 Inch Sheet (L-T Orientation).  
Martin Marietta

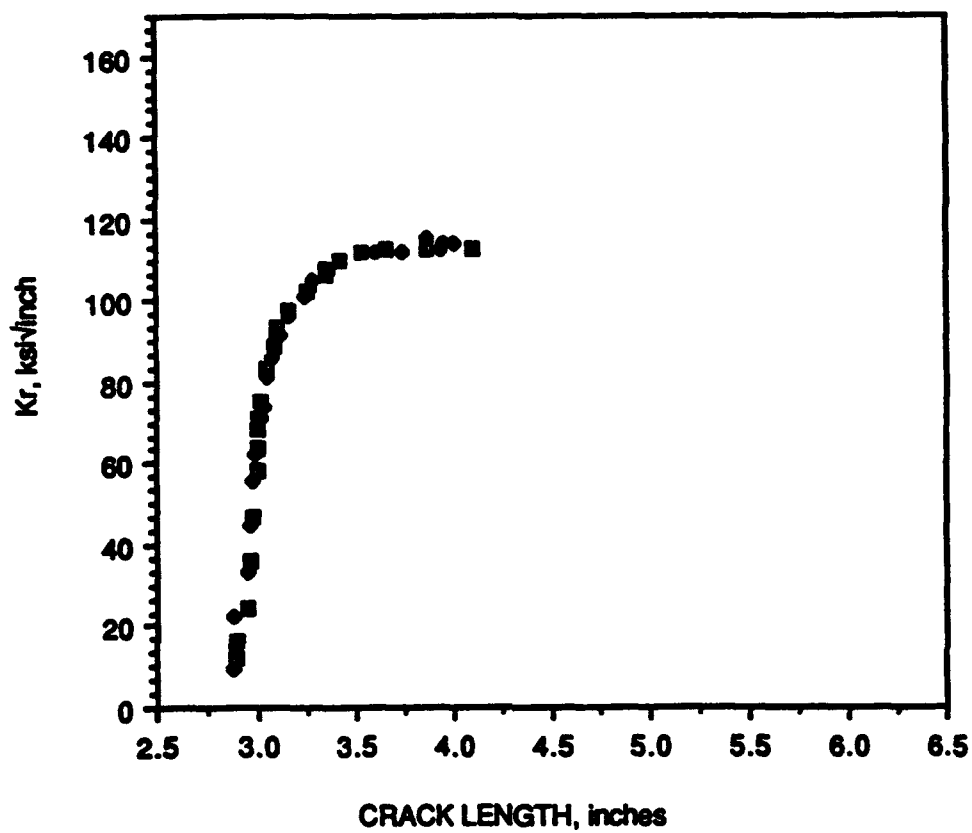


Figure K2. R-Curve Results for 2091-T3 0.144 Inch Sheet (T-L Orientation). Martin Marietta.

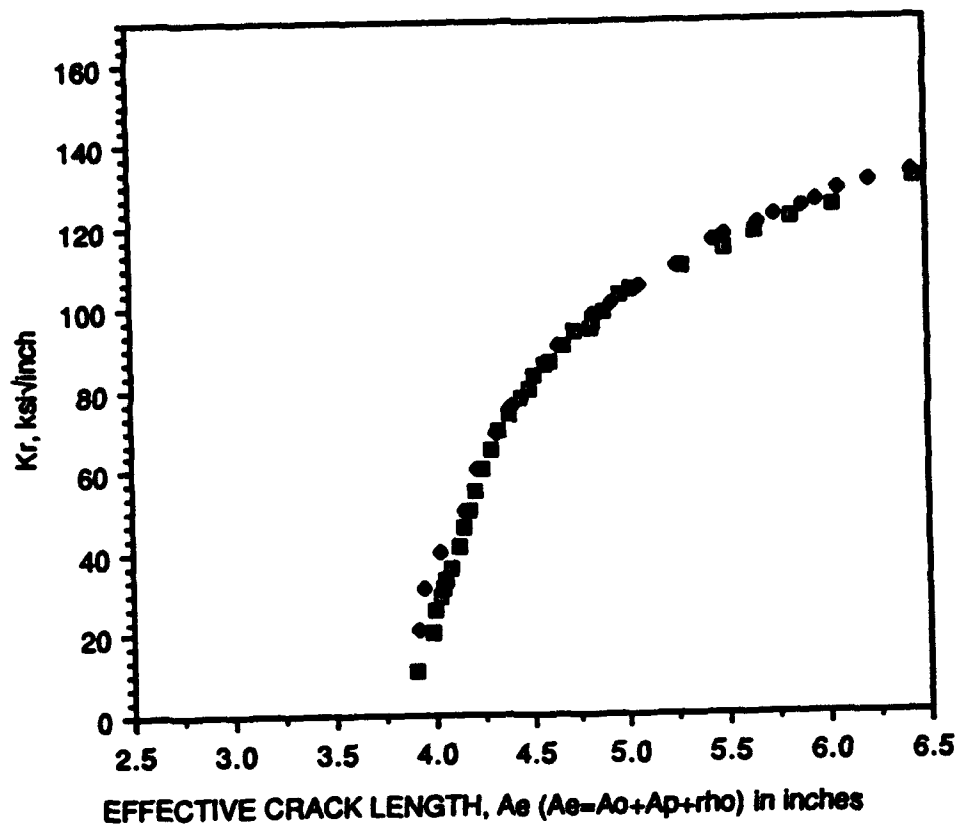
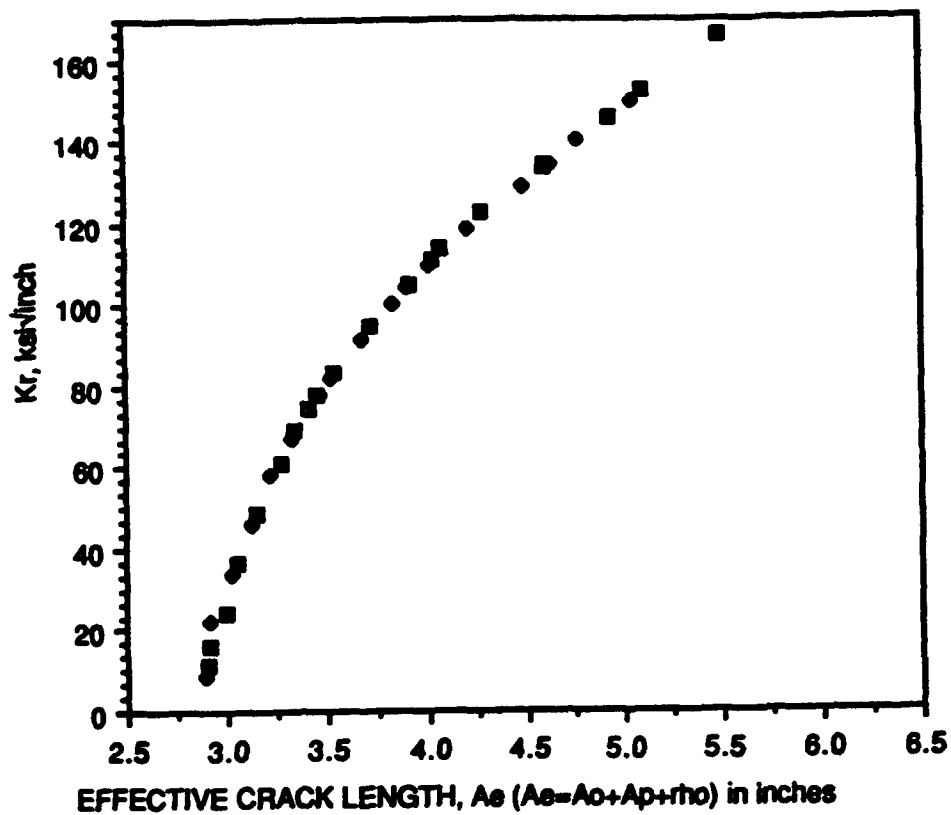


Figure K3. R-Curve Results for 2091-T3  
0.144 Inch Sheet with Effective Crack Length  
Adjusted for Plastic Zone (L-T Orientation)  
Martin Marietta.



**Figure K4. R-Curve Results for 2091-T3  
0.144 Inch Sheet with Effective Crack Length  
Adjusted for Plastic Zone (T-L Orientation)  
Martin Marietta.**

**TABLE K16**  
**R-CURVE DATA ASSOCIATED WITH**  
**FIGURES K1 AND K3 (SPECIMEN 3)**

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not adjusted	Adjusted for Plasticity
10	3.895	3.902	11	11
18	3.960	3.985	20	20
24	3.960	4.004	26	26
26	3.975	4.029	29	29
28	3.990	4.053	31	31
29	3.990	4.059	32	33
32	4.000	4.083	36	36
36	4.020	4.126	40	41
40	4.020	4.154	45	46
44	4.020	4.183	49	50
48	4.020	4.213	53	55
52	4.020	4.251	58	60
57	4.020	4.295	63	65
61	4.020	4.340	68	70
64	4.045	4.402	71	74
65	4.060	4.451	73	78
67	4.085	4.497	75	80
69	4.085	4.525	77	83
71	4.105	4.581	80	86
71	4.115	4.601	80	87
74	4.140	4.668	84	91
74	4.140	4.677	84	91
76	4.165	4.732	86	94
76	4.225	4.812	88	95
76	4.225	4.823	88	96
78	4.255	4.886	90	99
80	4.290	4.967	93	103
81	4.325	5.027	94	104
82	4.500	5.284	99	110
82	4.655	5.495	102	114
83	4.750	5.649	104	118
82	4.900	5.837	105	121
82	5.045	6.042	108	124
81	5.345	6.447	112	131

Thickness = .144 inch  
Yield = 49.7 ksi  
Specimen Width = 23.83 inch

**TABLE K17**  
**R-CURVE DATA ASSOCIATED WITH**  
**FIGURES K1 AND K3 (SPECIMEN 4)**

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not adjusted	Adjusted for Plasticity
10	3.895	3.902	11	11
19	3.895	3.924	21	21
28	3.895	3.956	31	31
36	3.930	4.032	39	40
44	4.000	4.163	49	50
52	4.000	4.231	58	60
60	4.010	4.319	67	69
65	4.040	4.416	73	76
69	4.080	4.523	77	83
74	4.110	4.641	84	91
78	4.200	4.823	90	98
79	4.260	4.921	92	101
80	4.350	5.058	95	105
82	4.480	5.262	99	110
84	4.575	5.440	102	116
84	4.615	5.492	102	117
84	4.735	5.663	105	120
84	4.800	5.754	106	122
84	4.890	5.883	107	124
84	4.945	5.956	107	125
84	5.025	6.072	109	128
84	5.135	6.223	111	130
82	5.320	6.435	111	132
81	5.490	6.661	114	135
79	5.730	6.962	115	138
74.5	6.265	7.660	117	144
74.5	6.440	7.932	118	152

Thickness = .144 inch  
Yield = 49.7 ksi  
Specimen Width = 23.81 inch

**TABLE K18**  
**R-CURVE DATA ASSOCIATED WITH**  
**FIGURES K2 AND K4 (SPECIMEN 1)**

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not adjusted	Adjusted for Plasticity
10	2.895	2.905	12	12
13	2.895	2.915	16	16
19	2.950	2.995	24	25
28	2.960	3.061	36	36
37	2.980	3.158	47	49
46	2.995	3.279	58	61
50	2.995	3.354	64	69
54	3.000	3.422	69	75
56	3.005	3.461	71	78
59	3.020	3.547	75	83
65	3.045	3.728	83	95
69	3.085	3.920	89	105
71	3.100	4.032	92	111
72	3.100	4.077	94	114
75	3.150	4.282	98	122
76	3.250	4.598	102	133
77	3.250	4.608	102	134
78	3.345	4.943	106	145
79	3.355	5.104	108	152
79	3.420	5.500	110	166
79	3.525		112	
77	3.655		113	
75	3.865		113	
71	4.100		113	

Thickness = .144 inch  
 Yield = 45.9 ksi  
 Specimen Width = 18.03 inch

**TABLE K19**  
**R-CURVE DATA ASSOCIATED WITH**  
**FIGURES K2 AND K4 (SPECIMEN 2)**

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not adjusted	Adjusted for Plasticity
8	2.880	2.886	10	9
18	2.880	2.918	22	22
26	2.950	3.036	33	34
36	2.950	3.122	45	46
44	2.975	3.231	56	58
49	2.990	3.331	63	67
56	3.020	3.477	71	78
58	3.025	3.530	74	82
63	3.050	3.687	81	92
67	3.075	3.837	86	100
68	3.080	3.901	88	104
70	3.115	4.025	92	110
73	3.150	4.214	96	119
75	3.240	4.499	101	129
76	3.260	4.627	103	134
78	3.275	4.766	105	140
78	3.365	5.054	107	149
79	3.425		110	
79	3.425		110	
78	3.540		112	
78	3.605		112	
76	3.735		112	
75	3.865		115	
73	3.940		113	
74	3.955		114	
73	4.000		114	

Thickness = .144 inch  
Yield = 45.9 ksi  
Specimen Width = 18.01 inch

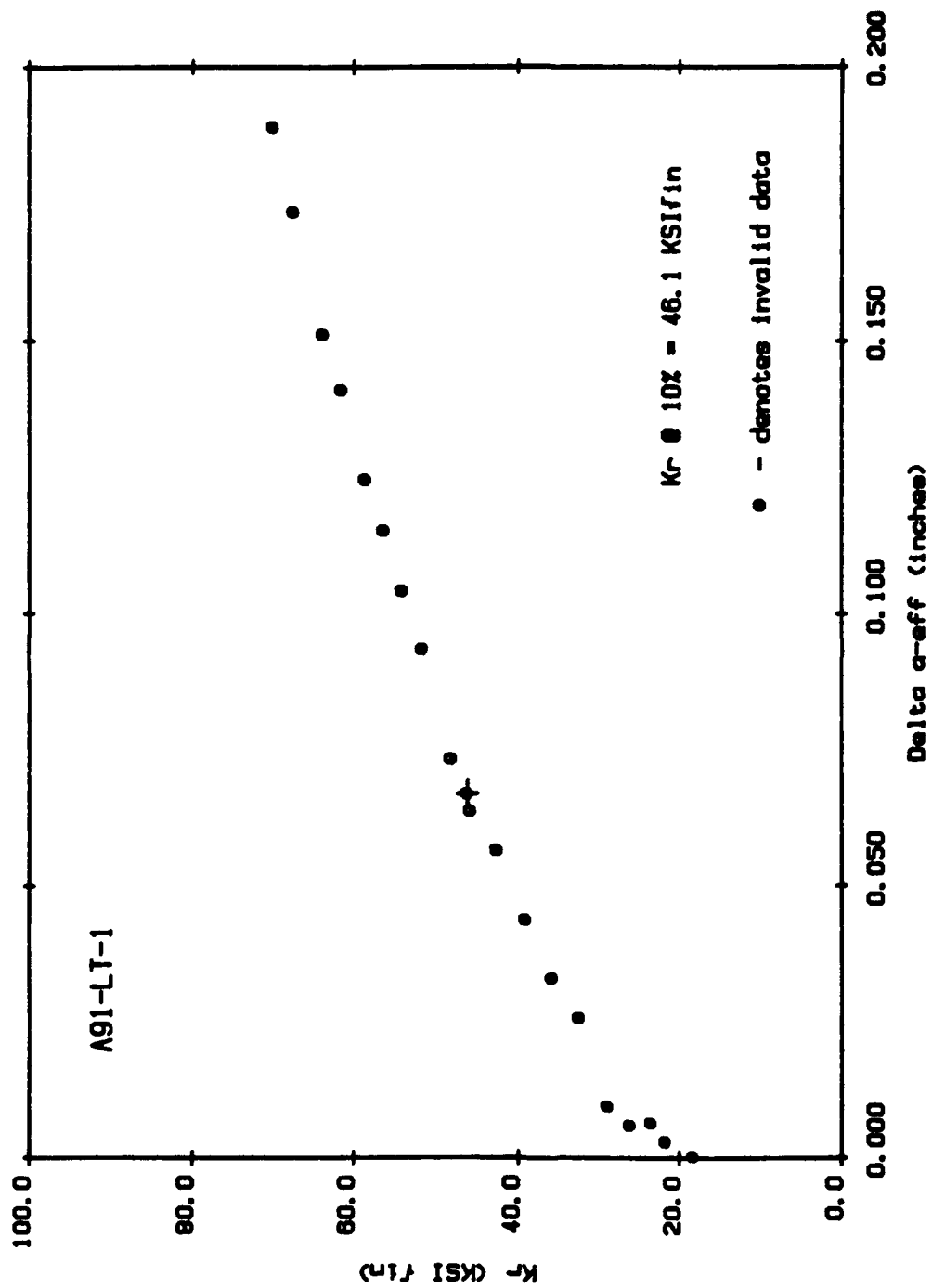


FIGURE K5. R-CURVE RESULTS FOR 2091-T3 0.144 INCH SHEET (L-T ORIENTATION). AIR FORCE.

TABLE K20

## R-CURVE DATA ASSOCIATED WITH

## FIGURE K5 (L-T ORIENTATION)

A91-LT-1 Oct 7, 1988

W = 2.509 inches

B = 0.143 inches

E = 12.760 MSI

YS = 51.000 KSI

Initial a (physical) = 1.046 inches

Initial a (compliance) = 1.044 inches

POINT	2V	P (LBF)	EB2V/P	a-eff/W	Nr	a-eff	delta a
1	***	initial compliance	crack length ***			1.0436	
1	0.0116	542	42.57	0.4160	18.22	1.0438	0.0003
2	0.0140	645	42.74	0.4171	21.74	1.0465	0.0030
3	0.0153	696	42.95	0.4185	23.57	1.0500	0.0064
4	0.0172	775	42.92	0.4183	26.22	1.0495	0.0060
5	0.0191	854	43.14	0.4197	29.01	1.0530	0.0095
6	0.0218	942	44.17	0.4262	32.57	1.0694	0.0258
7	0.0241	1029	44.64	0.4291	35.87	1.0767	0.0331
8	0.0265	1109	45.34	0.4334	39.10	1.0874	0.0438
9	0.0292	1192	46.21	0.4385	42.61	1.1002	0.0566
10	0.0315	1271	46.70	0.4413	45.79	1.1074	0.0638
11	0.0333	1321	47.37	0.4452	48.13	1.1170	0.0734
12	0.0360	1384	48.82	0.4532	51.57	1.1371	0.0935
13	0.0380	1434	49.62	0.4575	54.08	1.1479	0.1043
14	0.0398	1475	50.46	0.4619	56.34	1.1589	invalid
15	0.0416	1518	51.19	0.4656	58.59	1.1683	invalid
16	0.0440	1564	52.51	0.4722	61.52	1.1847	invalid
17	0.0459	1603	53.35	0.4762	63.81	1.1949	invalid
18	0.0490	1651	55.26	0.4851	67.47	1.2172	invalid
19	0.0512	1692	56.64	0.4913	70.04	1.2326	invalid
20	0.0565	1738	60.36	0.5068	75.90	1.2717	invalid
21	0.0597	1762	62.84	0.5165	79.32	1.2959	invalid
22	0.0660	1792	63.12	0.5353	85.79	1.3430	invalid
The following value is the 10% SECANT value							
23	0.0318	1275	46.92	0.4426	46.10	1.1105	0.0670

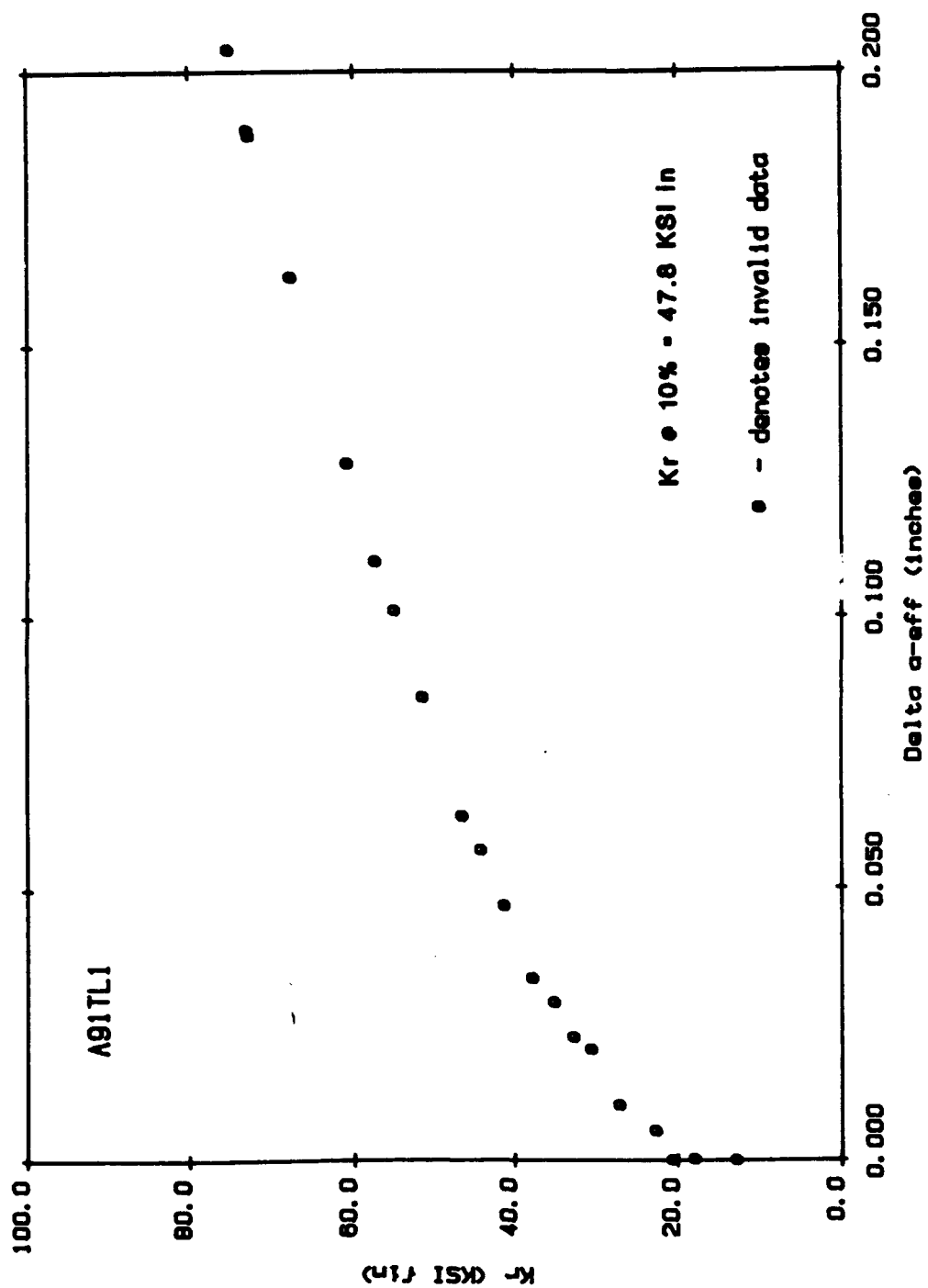


FIGURE K6. R-CURVE RESULTS FOR 2091-T3  
0.144 INCH SHEET (T-L Orientation).  
AIR FORCE.

## R-CURVE DATA ASSOCIATED WITH

**FIGURE K6 (T-L ORIENTATION)**

The following value is the 100 SECANT value

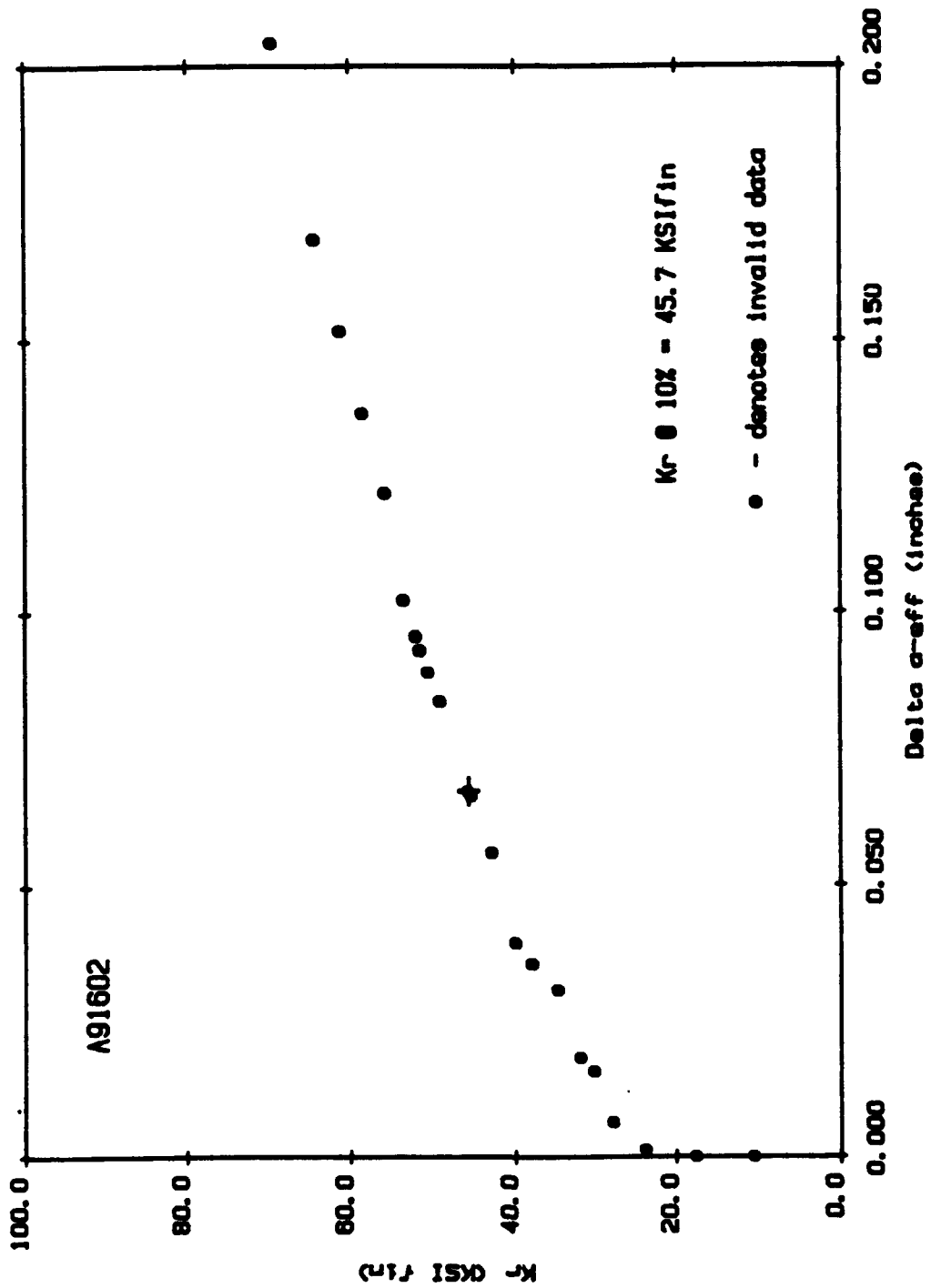


FIGURE K7. R-CURVE RESULTS for 2091-T3 0.144 Inch Sheet  
(60° Orientation, Specimen 1).  
Air Force.

## R-CURVE DATA ASSOCIATED WITH

**A91602 Oct 7, 1998**

W = 2.506 inches

2.309 inches  
0.143 inches

**0.143 INCH**  
**12.450 MSI**

15M 000.05 = 52A  
15M 12.450 MS1

YS = 50.000 KSI

Initial a (physical) = 1.109 inches  
Initial a (compilance) = 1.105 inches

Initial a (compliance) = 1.106 inches

POINT	2V	P (LBF)	EB2V/P	s-eff/W	Kr	s-eff	delta s
1	***	initial compliance	crack length ***			1.1065	
1	0.0063	292	46.08	0.4378	10.39	1.0968	-0.0097
2	0.0115	489	46.35	0.4393	17.49	1.1007	-0.0058
3	0.0161	656	46.83	0.4421	23.66	1.1077	0.0012
4	0.0190	764	47.19	0.4442	27.70	1.1129	0.0064
5	0.0209	821	47.86	0.4479	30.10	1.1222	0.0157
6	0.0222	866	48.04	0.4489	31.82	1.1247	0.0183
7	0.0244	930	48.95	0.4539	34.68	1.1372	0.0307
8	0.0268	1011	49.31	0.4558	37.87	1.1420	0.0355
9	0.0283	1060	49.59	0.4573	39.89	1.1454	0.0393
10	0.0307	1116	50.86	0.4639	42.82	1.1623	0.0558
11	0.0327	1168	51.64	0.4641	45.34	1.1728	0.0663
12	0.0357	1238	53.10	0.4750	49.03	1.1902	0.0837
13	0.0377	1294	53.89	0.4788	51.45	1.1996	0.0931
14	0.0369	1266	53.55	0.4772	50.47	1.1955	0.0890
15	0.0391	1293	54.11	0.4798	51.93	1.2021	0.0956
16	0.0394	1321	54.67	0.4824	53.48	1.2087	0.1022
17	0.0414	1343	56.42	0.4903	55.69	1.2284	0.1219
18	0.0437	1384	57.76	0.4961	58.41	1.2430	0.1365
19	0.0461	1422	59.20	0.5021	61.10	1.2580	0.1516
20	0.0488	1463	60.86	0.5088	64.21	1.2749	0.1684
21	0.0536	1508	64.64	0.5231	69.27	1.3106	0.2042
22	0.0605	1530	71.77	0.5471	76.10	1.3706	0.2642
23	0.0680	1515	81.30	0.5741	82.92	1.4384	0.3319
24	0.0330	1175	51.76	0.4684	45.67	1.1737	0.0672

The following value is the 10% SECANT value

The following value is the 10% SECANT value

0.0330	1175	51.76	0.4684
--------	------	-------	--------

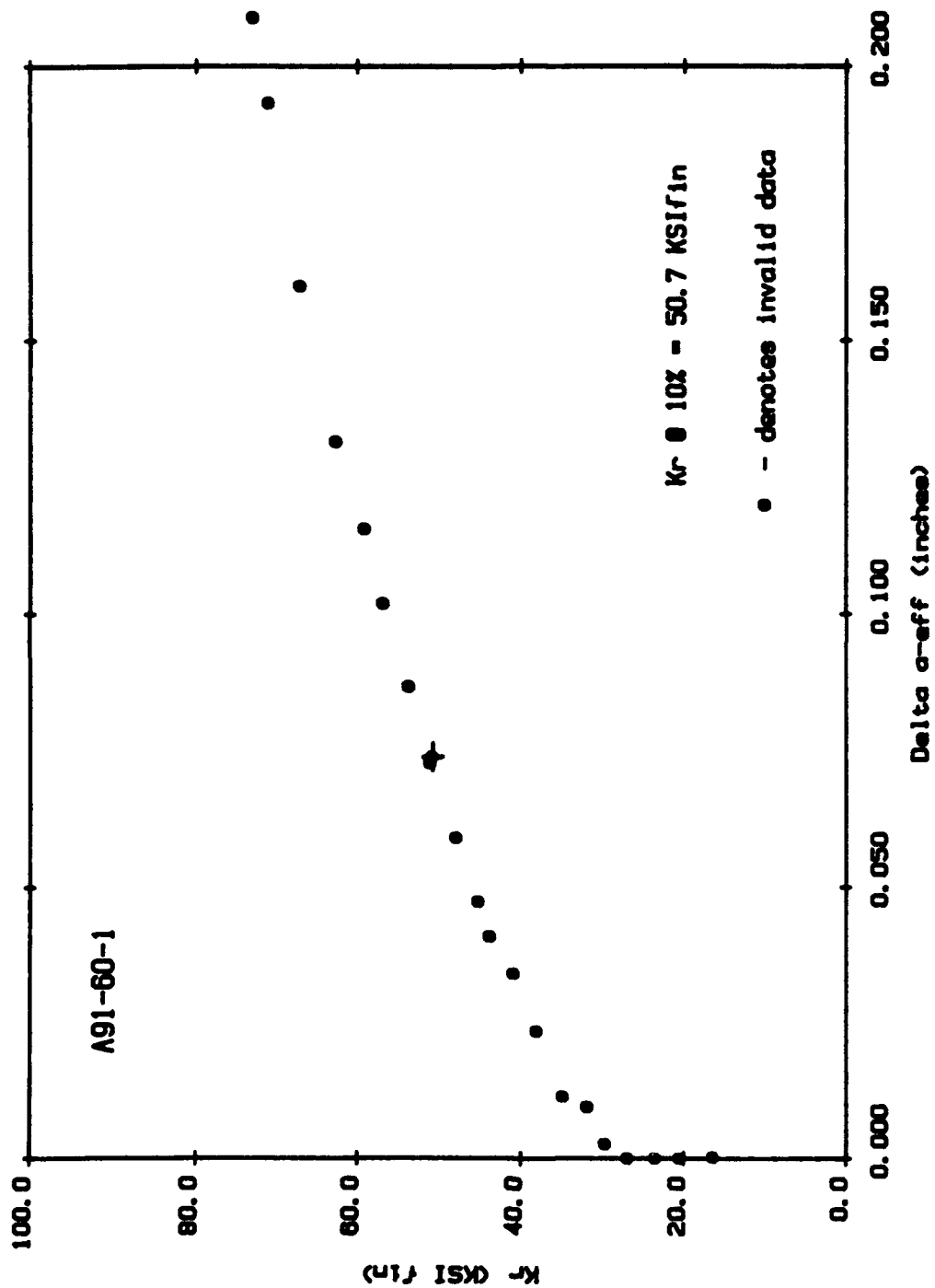


FIGURE K8. R-CURVE RESULTS FOR 2091-T3  
0.144 INCH SHEET (60° ORIENTATION,  
SPECIMEN 2). AIR FORCE

TABLE K23

R-CURVE DATA ASSOCIATED WITH FIGURE K8  
(60° ORIENTATION, SPECIMEN 2)

A91-60-1 Oct 7, 1988

W = 2.508 inches

B = 0.143 inches

E = 11.980 MSI

YS = 50.000 KSI

Initial a (physical) = 1.036 inches

Initial a (compliance) = 1.034 inches

POINT	2V	P (LBF)	EB <sub>2V</sub> /P	a-eff/W	Mr	a-eff	delta a
1	***	initial compliance	crack length ***			1.0343	
1	0.0106	493	42.05	0.4125	16.32	1.0346	0.0002
2	0.0136	622	41.66	0.4099	20.46	1.0280	-0.0063
3	0.0159	709	42.03	0.4124	23.49	1.0342	-0.0001
4	0.0184	815	41.84	0.4112	26.92	1.0311	-0.0032
5	0.0205	893	42.19	0.4135	29.67	1.0369	0.0026
6	0.0222	952	42.60	0.4162	31.86	1.0438	0.0095
7	0.0244	1038	42.72	0.4170	34.80	1.0457	0.0114
8	0.0269	1119	43.48	0.4218	38.03	1.0579	0.0236
9	0.0291	1189	44.15	0.4261	40.85	1.0685	0.0342
10	0.0313	1263	44.59	0.4288	43.73	1.0753	0.0410
11	0.0325	1294	45.00	0.4313	45.13	1.0816	0.0473
12	0.0346	1354	45.77	0.4359	47.80	1.0933	0.0590
13	0.0372	1421	46.71	0.4414	50.96	1.1070	0.0727
14	0.0394	1472	47.69	0.4470	53.60	1.1210	0.0867
15	0.0421	1533	48.80	0.4531	56.77	1.1362	0.1019
16	0.0441	1570	49.82	0.4585	59.09	1.1499	0.1156
17	0.0471	1636	51.05	0.4649	62.66	1.1658	0.1315
18	0.0512	1696	53.35	0.4762	67.17	1.1943	0.1600
19	0.0550	1725	56.24	0.4895	71.07	1.2276	0.1933
20	0.0569	1740	57.68	0.4957	73.03	1.2432	0.2089
21	0.0771	1765	76.54	0.5612	91.85	1.4074	0.3731
22	0.0370	1411	46.79	0.4419	50.66	1.1081	0.0738

The following value is the 10% SECANT value

22 0.0370 1411 46.79 0.4419 50.66 1.1081 0.0738

invalid  
invalid  
invalid  
invalid  
invalid  
invalid  
invalid

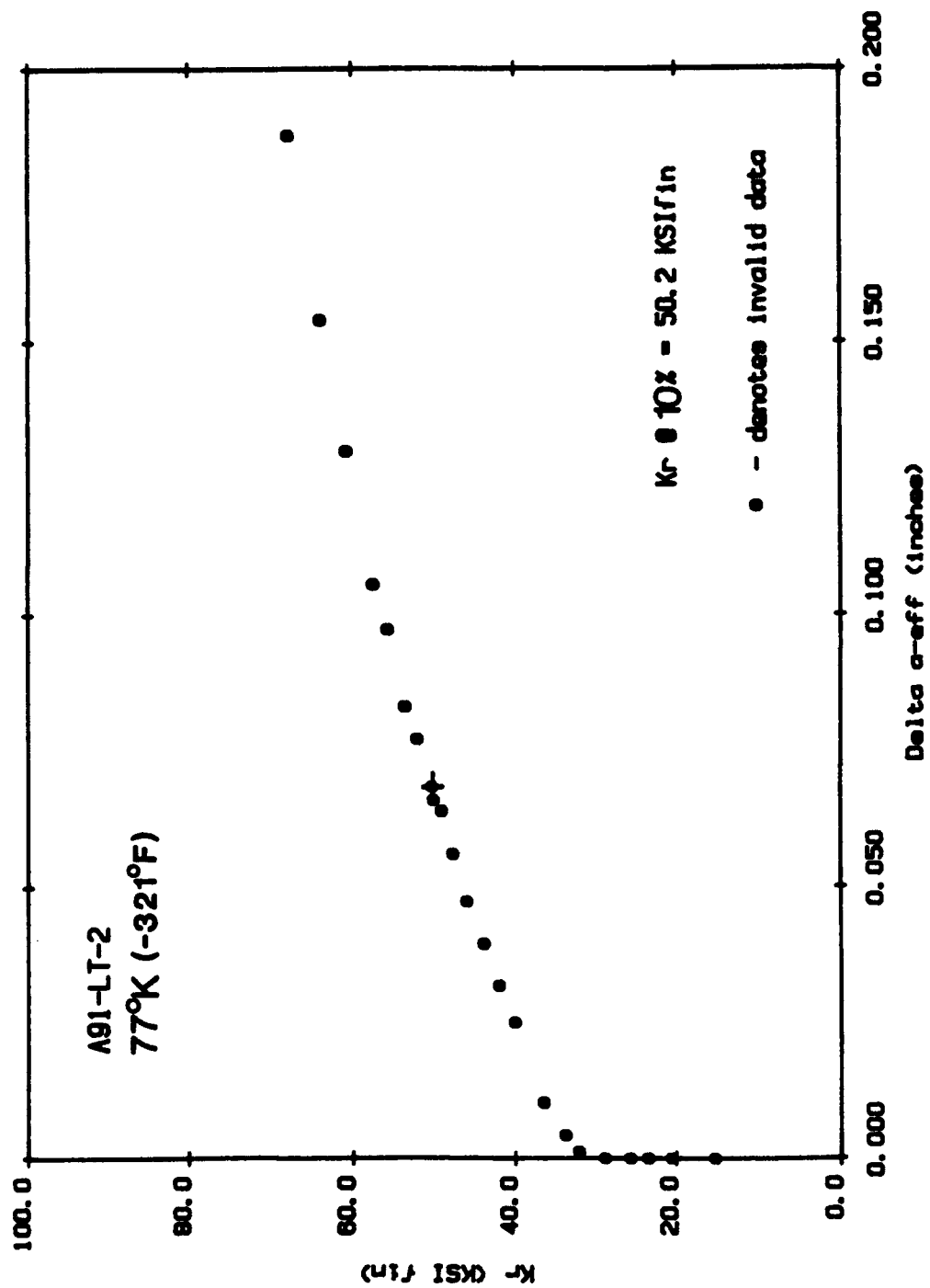


FIGURE K9. R-CURVE RESULTS FOR 2091-T3  
0.144 INCH SHEET (L-T ORIENTATION,  
-321°F). AIR FORCE.

TABLE K24

R-CURVE DATA ASSOCIATED WITH FIGURE K9  
(L-T ORIENTATION, -321°F)

A91-LT-2 7 Oct, 1988

W = 2.501 inches

B = 0.144 inches

E = 13.690 MSI

YS = 51.000 KSI

Initial a (physical) = 1.031 inches

Initial a (compliance) = 1.029 inches

POINT	2V	P (LBP)	RB2V/P	a-eff/W	Kr	a-eff	delta a
1	0.0034	564	42.35	0.4106	15.09	1.0287	0.0000
2	0.0088	460	41.75	0.4105	15.15	1.0266	-0.0021
3	0.0121	624	41.34	0.4078	20.38	1.0197	-0.0089
4	0.0140	708	41.69	0.4102	23.27	1.0257	-0.0030
5	0.0154	778	41.47	0.4087	25.49	1.0219	-0.0067
6	0.0175	872	41.62	0.4097	28.64	1.0244	-0.0043
7	0.0196	965	41.94	0.4118	31.89	1.0299	0.0012
8	0.0207	1014	42.12	0.4130	33.59	1.0328	0.0042
9	0.0225	1089	42.49	0.4154	36.32	1.0389	0.0102
10	0.0250	1178	43.40	0.4214	39.91	1.0537	0.0251
11	0.0264	1228	43.83	0.4241	41.91	1.0604	0.0318
12	0.0277	1272	44.33	0.4272	43.81	1.0682	0.0396
13	0.0292	1323	44.84	0.4303	45.93	1.0761	0.0474
14	0.0304	1359	45.41	0.4338	47.65	1.0848	0.0561
15	0.0314	1387	45.94	0.4369	49.05	1.0925	0.0639
16	0.0321	1412	46.07	0.4377	50.04	1.0945	0.0659
17	0.0335	1449	46.85	0.4422	52.01	1.1058	0.0771
18	0.0346	1481	47.27	0.4446	53.50	1.1117	0.0831
19	0.0362	1515	48.29	0.4503	55.61	1.1260	0.0973
20	0.0375	1550	48.89	0.4536	57.43	1.1342	0.1056
21	0.0402	1594	50.76	0.4634	60.74	1.1587	0.1301
22	0.0427	1630	52.67	0.4729	63.84	1.1826	0.1540
23	0.0459	1660	55.56	0.4865	67.66	1.2164	0.1878
24	0.0491	1678	58.69	0.5000	71.29	1.2504	0.2217
25	0.0548	1678	65.36	0.5257	77.31	1.3146	0.2859
26	0.0564	1651	68.39	0.5362	78.74	1.3408	0.3121
27	0.0322	1412	46.24	0.4387	50.17	1.0970	0.0683

The following value is the 10% SECANT value

invalid  
invalid  
invalid  
invalid  
invalid  
invalid  
invalid  
invalid  
invalid

TABLE K25

FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR  
ALCOA 2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
MCDONNELL DOUGLAS	LONG	50.2	65,600 +
ASTRO., CA		45.2	209,000 +
		42.0	67,000
		40.0	353,000 +
		38.1	670,000 +
		35.9	84,400 @
		35.7	45,700 #
		33.1	120,000 @
		30.9	340,000
		29.1	1,000,000 *

(\*): INDICATES A RUN-OUT TEST  
 (#): INDICATES FAILURE AT PIN HOLE  
 (@): INDICATES FAILURE AT RADIUS  
 (+): INDICATES SPECIMENS WERE RECONFIGURED AND  
 HAD SURFACE COATING REMOVED

TABLE K26

FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR  
ALCOA 2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
MCDONNELL DOUGLAS	L TRANS	49.9	42,300 +
ASTRO., CA		45.0	87,700 #+
		45.0	39,900
		39.8	293,000 +
		35.0	1,000,000 **
		34.9	385,000 !
		33.0	203,000 !
		33.0	621,000 !
		30.9	1,530,000 *!

(\*): INDICATES A RUN-OUT TEST  
 (#): INDICATES FAILURE AT PIN HOLE  
 (!): INDICATES THE SPECIMENS WERE ONLY RECONFIGURED  
 (+): INDICATES SPECIMENS WERE RECONFIGURED AND  
 HAD SURFACE COATING REMOVED

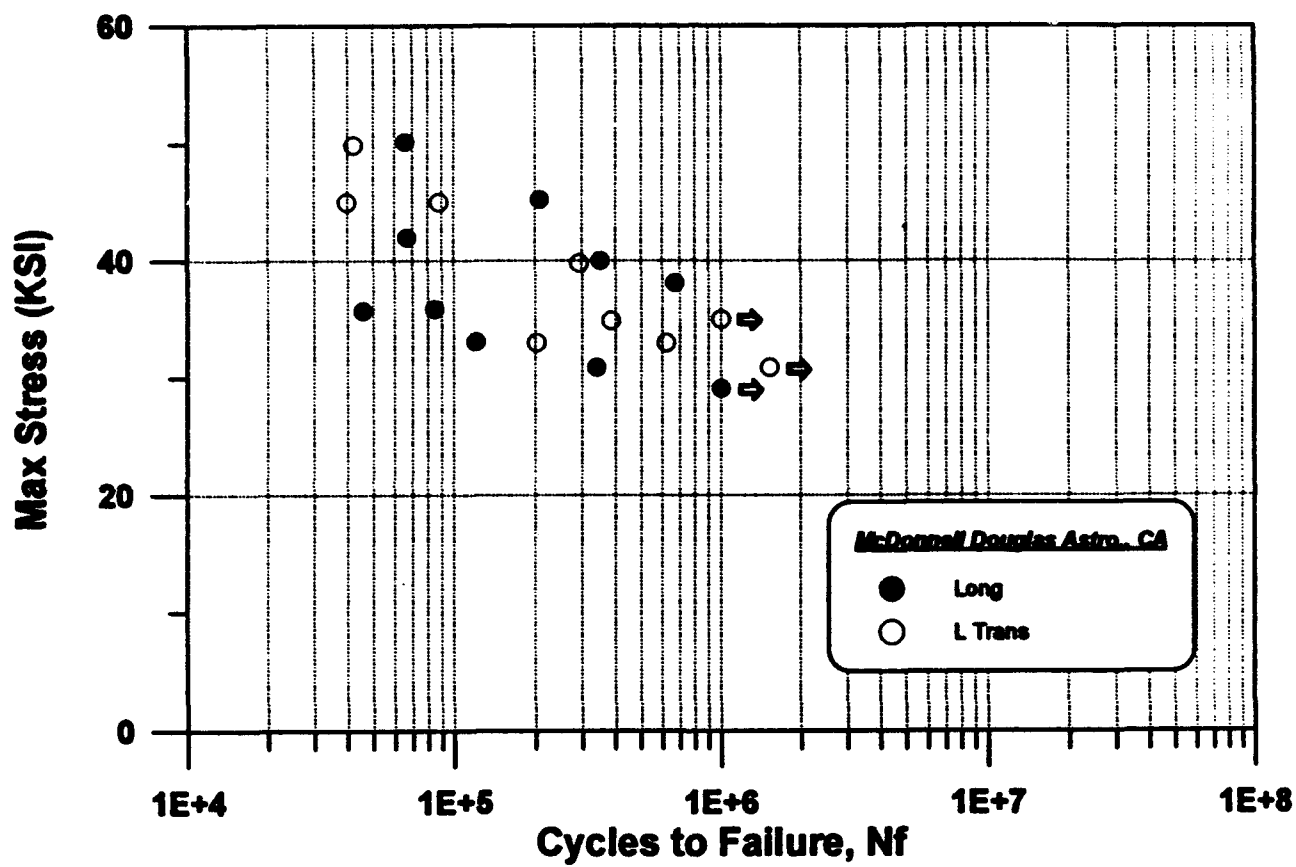


FIGURE K10. FATIGUE RESULTS FOR 2091-T3  
0.144 INCH SHEET (R=1.0, K<sub>t</sub> =1.0).  
MCDONNELL DOUGLAS ASTRONAUTICS

TABLE K27

FATIGUE RESULTS WITH R=0.1 AND K<sub>t</sub>=3.0 FOR  
ALCOA 2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
MCDONNELL DOUGLAS	LONG	24.9	16,100
ASTRO., CA		21.9	32,200
		19.9	109,000
		18.0	112,000
		18.0	71,250
		15.0	294,000
		14.9	1,000,000 *
		14.0	1,000,000 *
		13.0	1,000,000 *

(\*): INDICATES A RUN-OUT TEST

TABLE K28

FATIGUE RESULTS WITH R=0.1 AND K<sub>t</sub>=3.0 FOR  
ALCOA 2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
MCDONNELL DOUGLAS	L TRANS	29.9	10,800
ASTRO., CA		28.1	11,200
		26.8	23,700
		25.1	34,900
		22.1	58,700
		19.9	87,400
		18.0	135,000
		16.0	247,000
		14.9	1,000,000

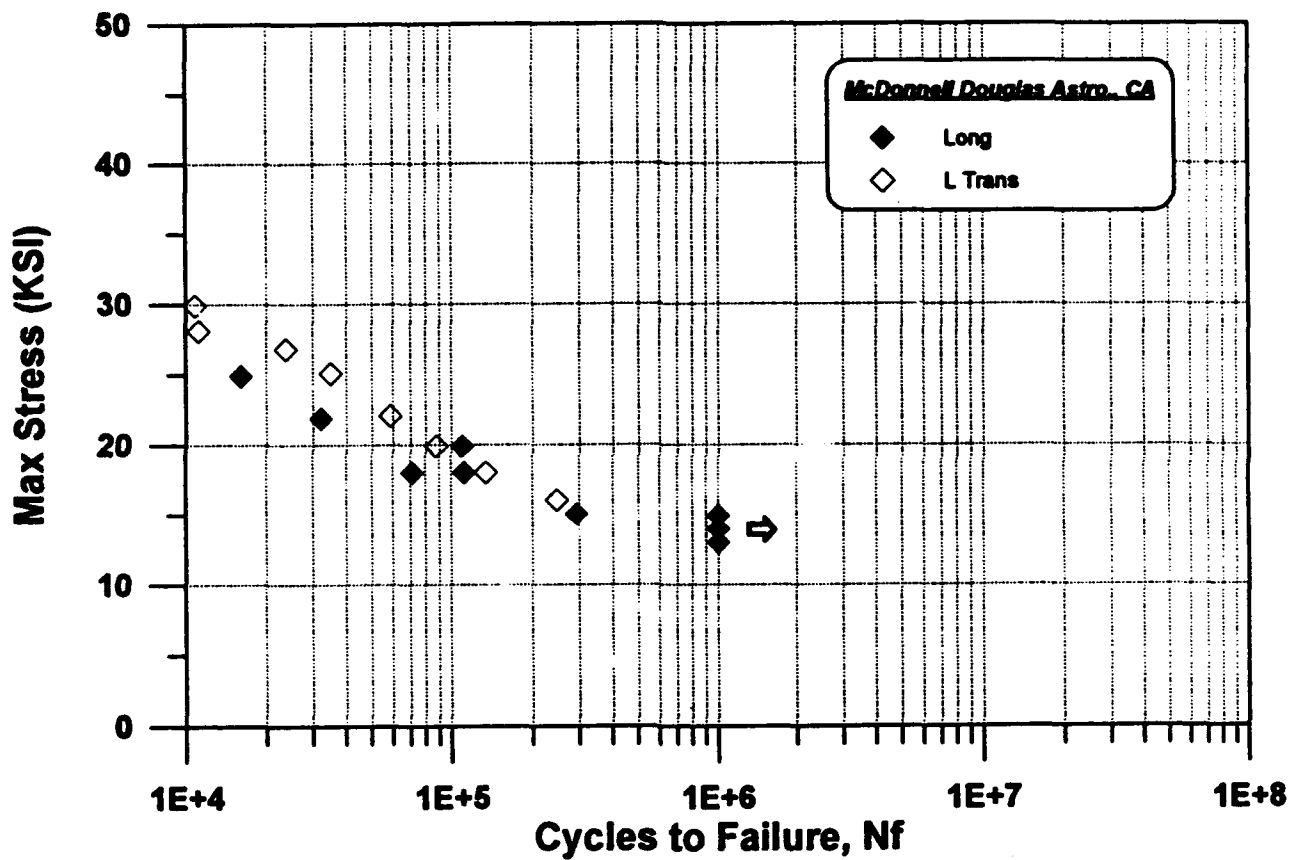


FIGURE K11. FATIGUE RESULTS FOR 2091-T3  
0.144 INCH SHEET ( $R=1.0$ ,  $K_t=3.0$ ).  
MCDONNELL DOUGLAS ASTRONAUTICS

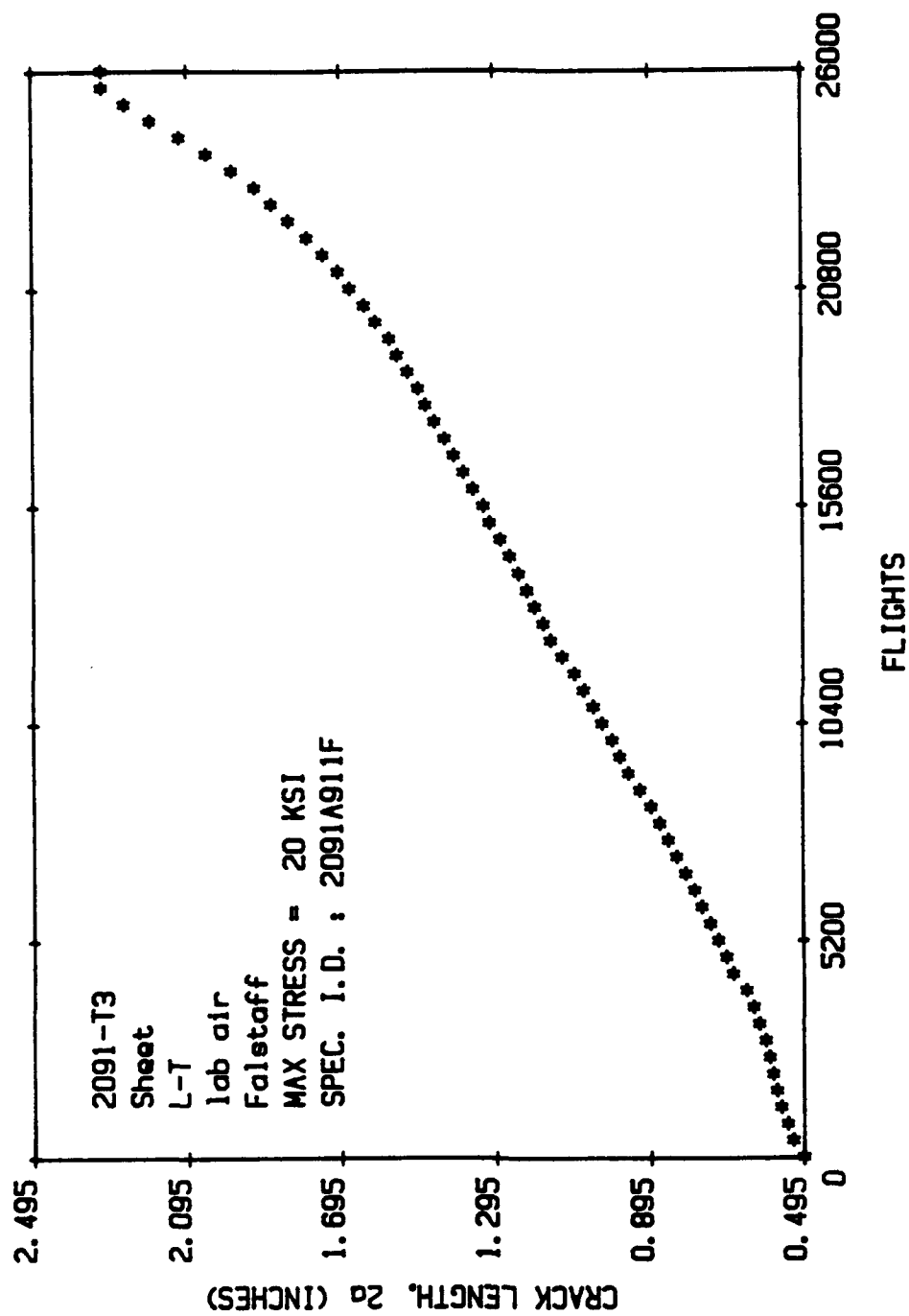


FIGURE K12. FALSTAFF SPECTRUM FATIGUE CRACK LENGTH  
VS FLIGHTS DATA FOR 2091-T3 0.144  
INCH SHEET, AIR FORCE.

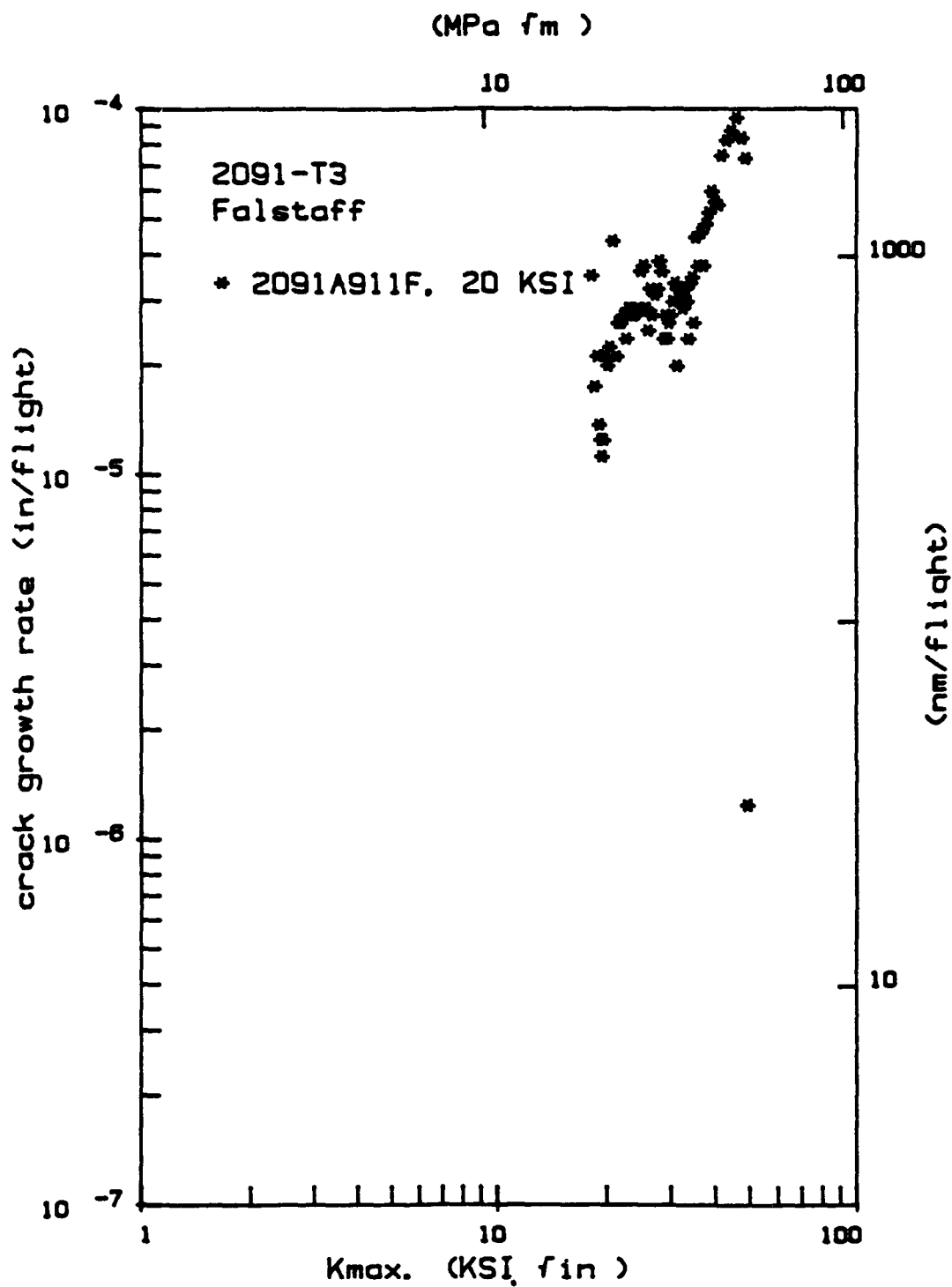


FIGURE K13. FALSTAFF SPECTRUM FATIGUE CRACK  
 GROWTH RATE VS KMAX DATA FOR  
 2091-T3 0.144 INCH SHEET.  
 AIR FORCE.

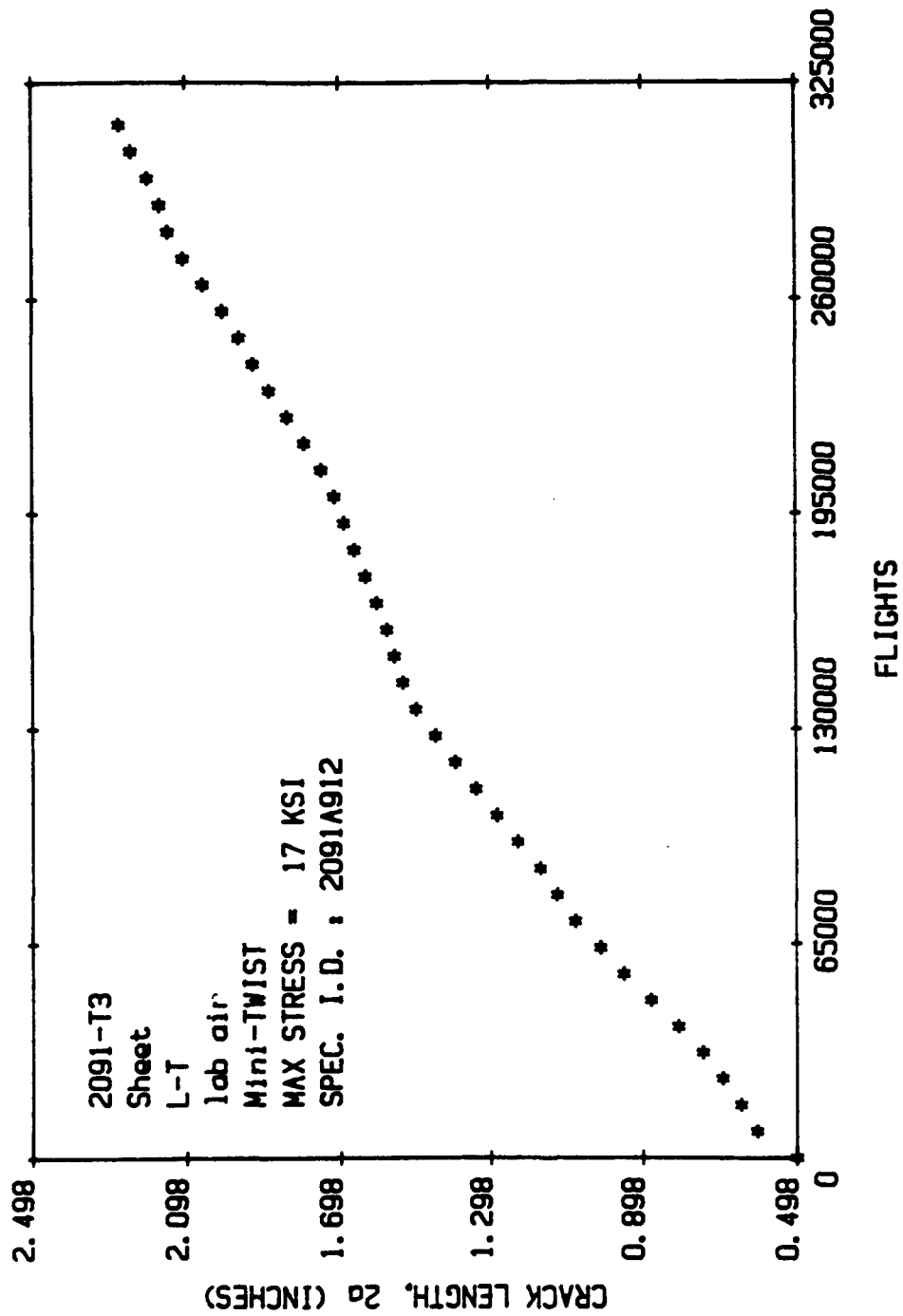


FIGURE K14. MINI-TWIST SPECTRUM FATIGUE CRACK LENGTH  
VS FLIGHTS DATA FOR 2091-T3 0.144  
INCH SHEET(SPECIMEN #2091A912)

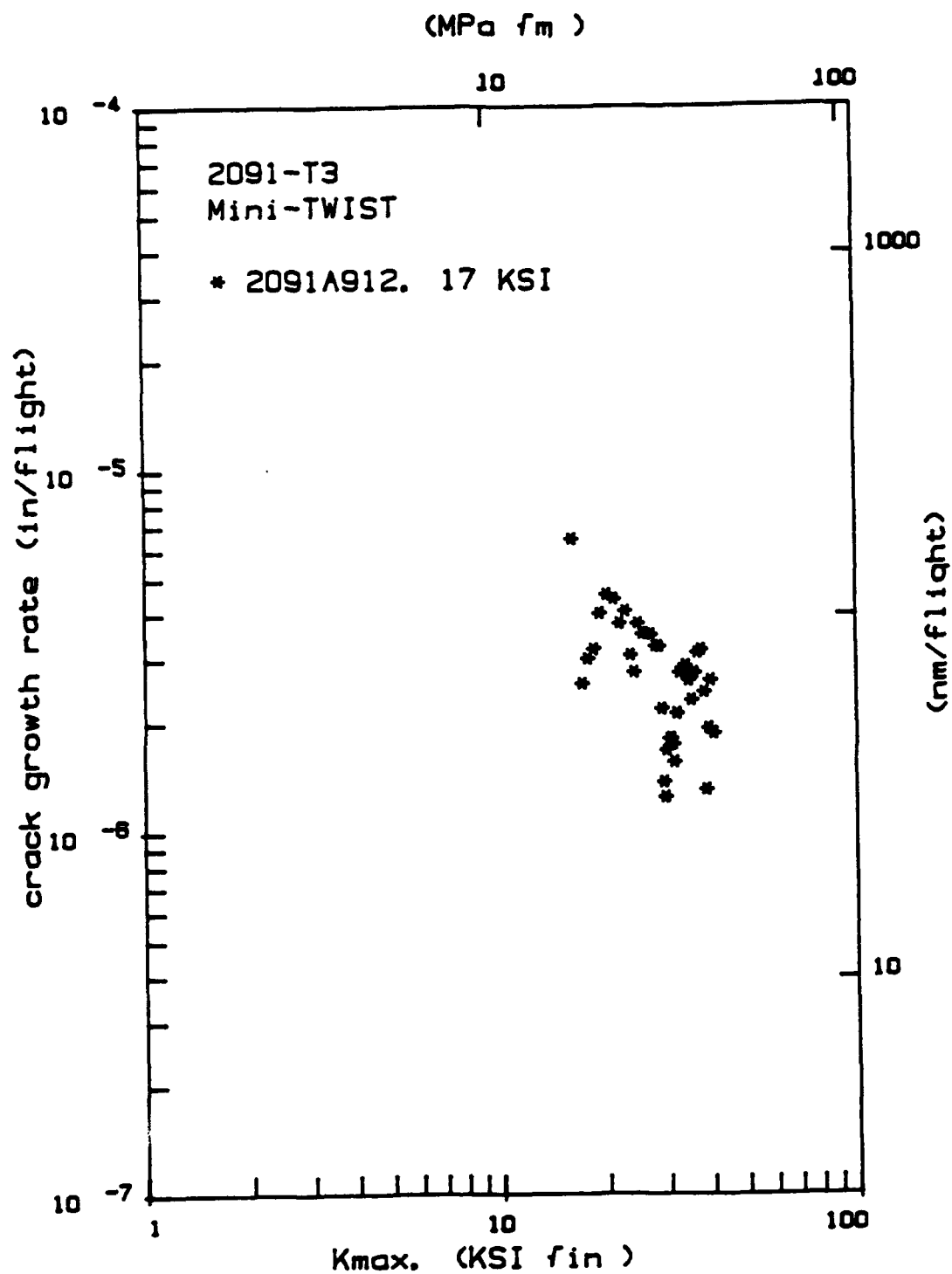


FIGURE K15. MINI-TWIST SPECTRUM CRACK GROWTH RATE  
VS KMAX DATA FOR 2091-T3  
0.144 INCH SHEET  
(Specimen #2091A912).  
AIR FORCE. 372

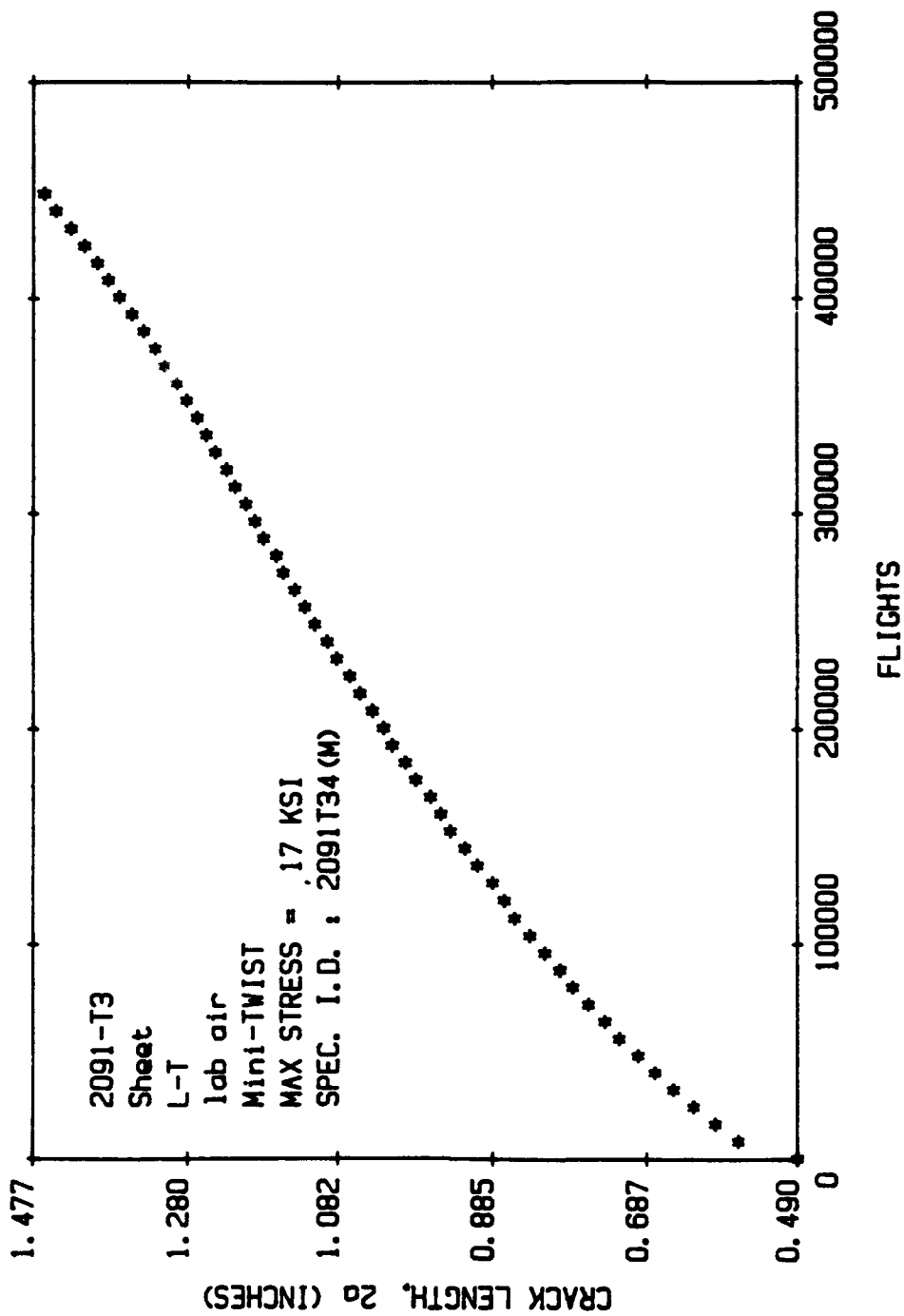


FIGURE K16. MINI-TWIST SPECTRUM FATIGUE CRACK LENGTH  
VS FLIGHTS DATA FOR 2091-T3 0.144  
INCH SHEET(SPECIMEN #2091T34M).  
AIR FORCE.

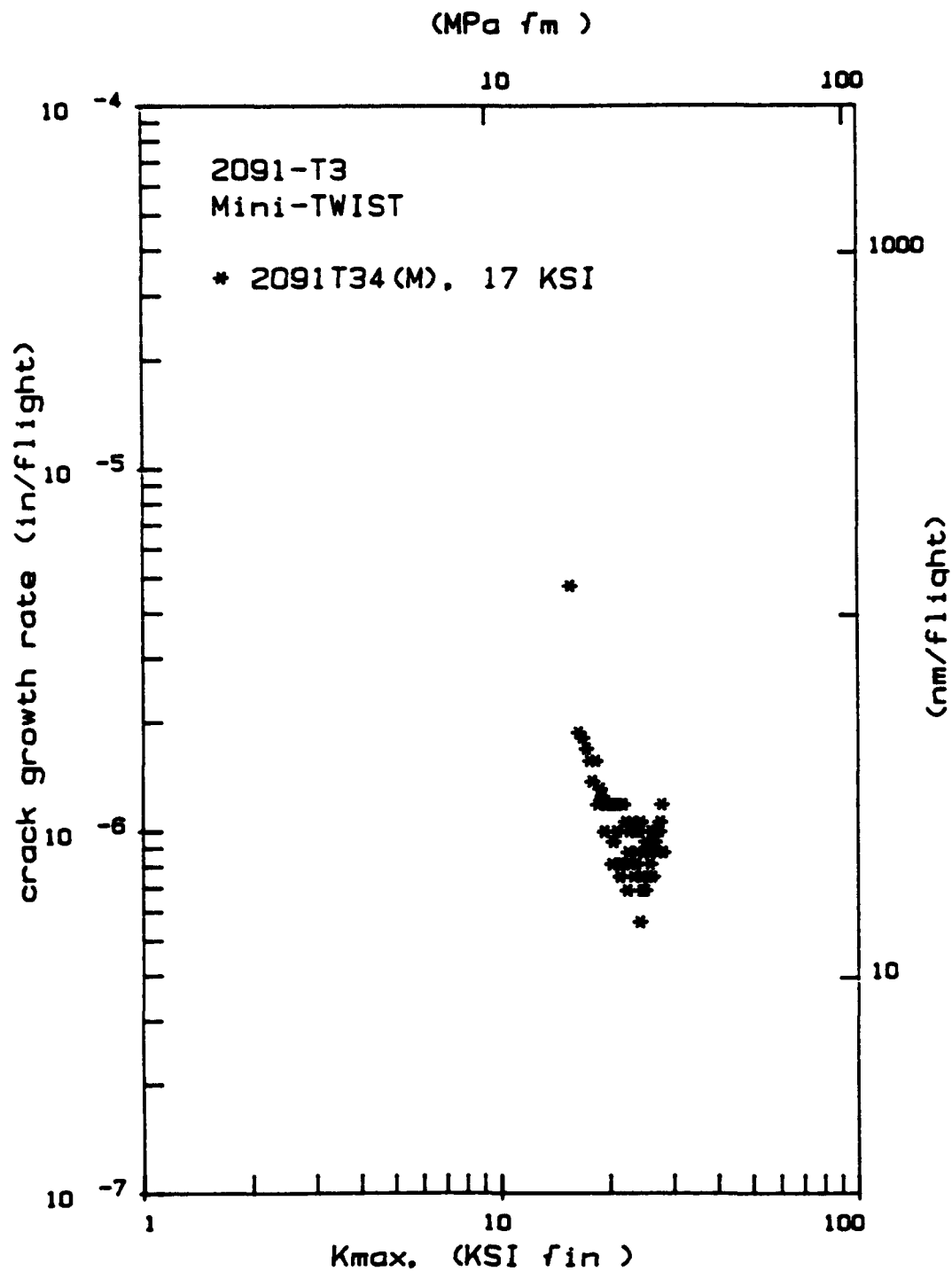


FIGURE K17. MINI-TWIST SPECTRUM CRACK GROWTH RATE VS KMAX DATA FOR 2091-T3 0.144 INCH SHEET (SPECIMEN #2091T34M). AIR FORCE.

TABLE K29

## TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 16 HOURS AT 335 F

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
GENERAL DYNAMICS, TEXAS	RT	LONG	67.3	56.1	14.2		
			67.1	56.3	14.3		
		AVERAGE	67.2	56.2	14.3		
		STANDARD DEVIATION	0.1	0.1	0.1		

TABLE K30

## TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 16 HOURS AT 335 F

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
GENERAL DYNAMICS, TEXAS	RT	45	65.3	46.7	19.2		
			65.6	47.4	19.8		
	AVERAGE		65.5	47.1	19.5		
	STANDARD DEVIATION		0.2	0.5	0.4		

TABLE K31

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 16 HOURS AT 335 F

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
GENERAL DYNAMICS, TEXAS	RT	L TRANS	70.7	51.3	12.8		
			70.9	52.8	11.1		
		AVERAGE	70.8	52.1	12.0		
		STANDARD DEVIATION	0.1	1.1	1.2		

TABLE K32

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 32 HOURS AT 335 F

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
-----							
GENERAL DYNAMICS, TEXAS	RT	LONG	69.6	58.8			
			69.9	59.4	15.3		
		AVERAGE		69.8	59.1	15.3	
	STANDARD DEVIATION		0.2	0.4			

TABLE K33

## TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 32 HOURS AT 335 F

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
-----							
GENERAL DYNAMICS, TEXAS	RT	45	68.8	51.9	17.9		
			68.1	51.1	18.5		
		AVERAGE	68.5	51.5	18.2		
		STANDARD DEVIATION	0.5	0.6	0.4		

TABLE K34

## TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 32 HOURS AT 335 F

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
GENERAL DYNAMICS, TEXAS	RT	L TRANS	73.9	57.0	15.6		
			74.5	54.5	14.3		
		AVERAGE	74.2	55.8	15.0		
		STANDARD DEVIATION	0.4	1.8	0.9		

TABLE K35  
KAHN TEAR TEST RESULTS FOR ALCOA  
2091-T3 SHEET (0.144" X 48" X 48")  
AGED 16 HOURS AT 335 F

COMPANY	ORIENTATION	TEAR STRENGTH (KSI)
GENERAL DYNAMICS, TEXAS	L-T	81.4 78.8
AVERAGE		80.1
STANDARD DEVIATION		1.9

TABLE K36  
KAHN TEAR TEST RESULTS FOR ALCOA  
2091-T3 SHEET (0.144" X 48" X 48")  
AGED 16 HOURS AT 335 F

COMPANY	ORIENTATION	TEAR STRENGTH (KSI)
GENERAL DYNAMICS, TEXAS	45-45	74.6
AVERAGE		74.6
STANDARD DEVIATION		

**TABLE K37**

**KAHN TEAR TEST RESULTS FOR ALCOA  
2091-T3 SHEET (0.144" X 48" X 48")  
AGED 16 HOURS AT 335 F**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>TEAR STRENGTH (KSI)</b>
<hr/>		
<b>GENERAL DYNAMICS, TEXAS</b>	<b>T-L</b>	<b>78.2 77.3</b>
	<b>AVERAGE</b>	<b>77.7</b>
	<b>STANDARD DEVIATION</b>	<b>0.6</b>

**TABLE K38**

**KAHN TEAR TEST RESULTS FOR ALCOA  
2091-T3 SHEET (0.144" X 48" X 48")  
AGED 32 HOURS AT 335 F**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>TEAR STRENGTH (KSI)</b>
<hr/>		
<b>GENERAL DYNAMICS, TEXAS</b>	<b>L-T</b>	<b>76.4 74.6</b>
	<b>AVERAGE</b>	<b>75.5</b>
	<b>STANDARD DEVIATION</b>	<b>1.3</b>

TABLE K39

KAHN TEAR TEST RESULTS FOR ALCOA  
2091-T3 SHEET (0.144" X 48" X 48")  
AGED 32 HOURS AT 335 F

COMPANY	ORIENTATION	TEAR STRENGTH (KSI)
-----		
GENERAL DYNAMICS, TEXAS	45-45	73.7
		74.1
AVERAGE		73.9
STANDARD DEVIATION		0.2

TABLE K40

KAHN TEAR TEST RESULTS FOR ALCOA  
2091-T3 SHEET (0.144" X 48" X 48")  
AGED 32 HOURS AT 335 F

COMPANY	ORIENTATION	TEAR STRENGTH (KSI)
<hr/>		
GENERAL DYNAMICS, TEXAS	T-L	74.7
AVERAGE		74.7
STANDARD DEVIATION		

TABLE 41  
 TEAR-YIELD STRENGTH RATIOS FOR ALCOA  
 2091-T3 SHEET (0.144" X 48" X 48")  
 AGED 16 HOURS AT 335 F

COMPANY	TENSILE-TEAR ORIENTATION	TEAR-YIELD STRENGTH RATIO
GENERAL DYNAMICS, TEXAS	L/L-T	1.42
	LT/T-L	1.48
	45/45-45	1.58
	L/T-L	1.38

TABLE 42  
 TEAR-YIELD STRENGTH RATIOS FOR ALCOA  
 2091-T3 SHEET (0.144" X 48" X 48")  
 AGED 32 HOURS AT 335 F

COMPANY	TENSILE-TEAR ORIENTATION	TEAR-YIELD STRENGTH RATIO
GENERAL DYNAMICS, TEXAS	L/L-T	1.27
	LT/T-L	1.34
	45/45-45	1.44
	L/T-L	1.26

# Alcoa 2091 .144" Sheet

Aged 16/32 Hours at 335F

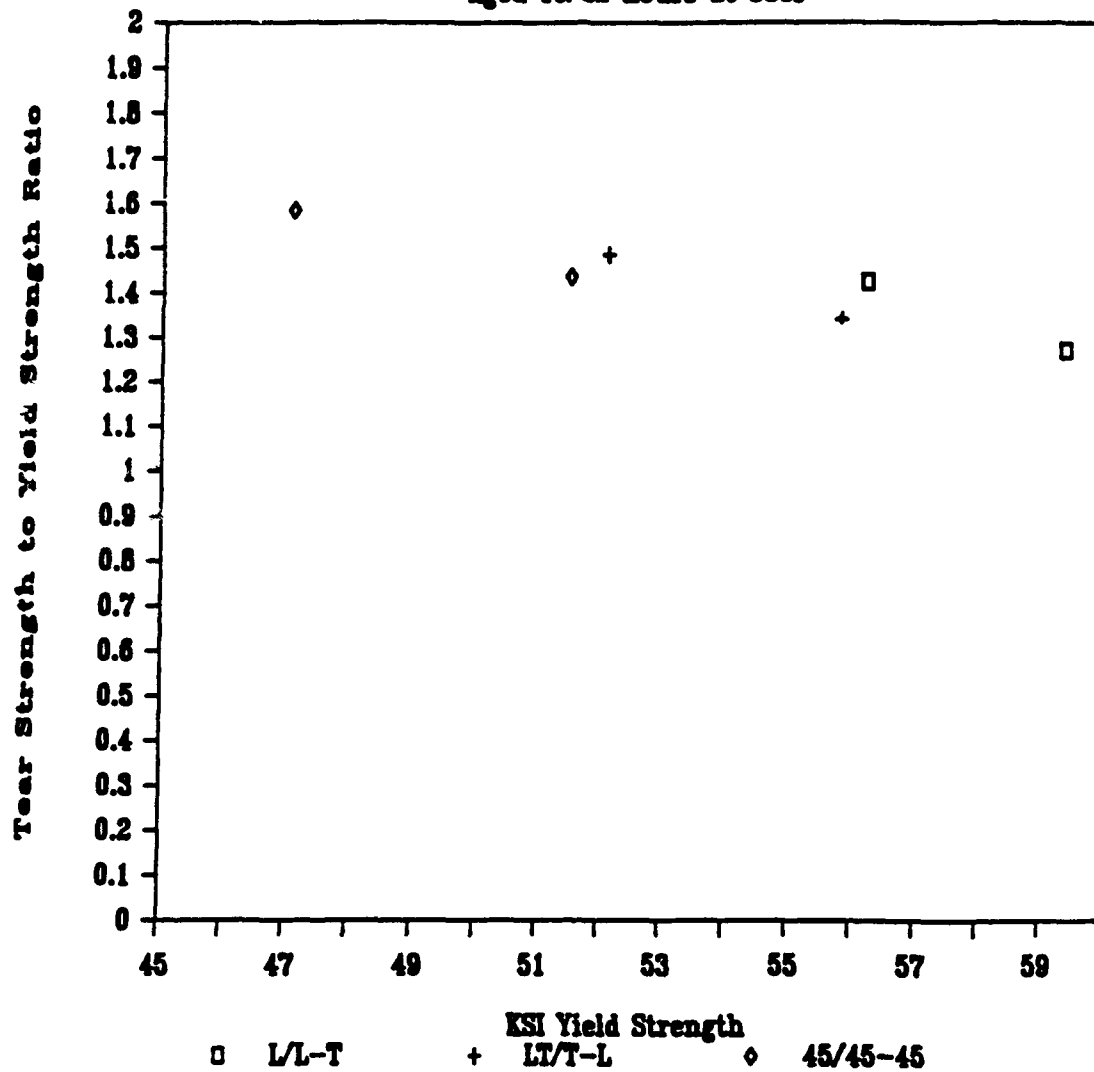


FIGURE K18. TEAR STRENGTH to YIELD STRENGTH RATIO VS YIELD STRENGTH DATA for 2091-T3 Aged 16/32 Hours at 335°F. General Dynamics.

TABLE K43

## TENSILE RESULTS FOR ALCOA

2091-T8X SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	LONG	63.4	53.5	15.6		10.8
			63.2	53.3	16.7		10.2
			63.7	53.7	14.7		10.5
			63.2	53.6	12.6		10.8
		AVERAGE	63.4	53.5	14.9		10.6
		STANDARD DEVIATION	0.2	0.2	1.7		0.3

TABLE K44

## TENSILE RESULTS FOR ALCOA

2091-T8X SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	45		44.3			10.4
			63.3	44.1	19.8		10.5
			62.4	43.5	17.8		11.8
			62.8	44.9	19.2		11.9
		AVERAGE	62.8	44.2	18.9		11.2
		STANDARD DEVIATION	0.5	0.6	1.0		0.8

TABLE K45

## TENSILE RESULTS FOR ALCOA

2091-T8X SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	L TRANS	67.5	48.7	12.1		10.6
			68.2	49.2	12.7		11.2
			67.8	48.8	13.1		11.3
		AVERAGE	67.8	48.9	12.6		11.0
		STANDARD DEVIATION	0.4	0.3	0.5		0.4

**TABLE K46**

**COMPRESSION RESULTS FOR ALCOA**

**2091-T8X SHEET (0.144" X 48" X 48")**

<b>COMPANY</b>	<b>TEST TEMPERATURE (DEGREES F)</b>	<b>ORIENTATION</b>	<b>COMPRESSIVE YIELD STRENGTH (KSI)</b>	<b>COMPRESSIVE MODULUS (KSI)</b>
<b>NORTHROP</b>	<b>RT</b>	<b>LONG</b>	<b>42.7</b>	<b>12.0</b>
			<b>42.5</b>	<b>11.5</b>
			<b>42.9</b>	<b>11.7</b>
		<b>AVERAGE</b>	<b>42.7</b>	<b>11.7</b>
		<b>STANDARD DEVIATION</b>	<b>0.3</b>	<b>0.2</b>

**TABLE K47**

**COMPRESSION RESULTS FOR ALCOA**

**2091-T8X SHEET (0.144" X 48" X 48")**

<b>COMPANY</b>	<b>TEST TEMPERATURE (DEGREES F)</b>	<b>ORIENTATION</b>	<b>COMPRESSIVE YIELD STRENGTH (KSI)</b>	<b>COMPRESSIVE MODULUS (KSI)</b>
<b>NORTHROP</b>	<b>RT</b>	<b>L TRANS</b>	<b>51.5</b>	<b>11.5</b>
			<b>51.4</b>	<b>11.3</b>
			<b>51.3</b>	<b>11.3</b>
		<b>AVERAGE</b>	<b>51.4</b>	<b>11.4</b>
		<b>STANDARD DEVIATION</b>	<b>0.1</b>	<b>0.1</b>

TABLE K48  
SLOTTED SHEAR RESULTS FOR ALCOA  
2091-T8X SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
<hr/>		
NORTHROP	LONG	40.6
		40.5
		40.5
	AVERAGE	40.5
	STANDARD DEVIATION	0.1

TABLE K49  
SLOTTED SHEAR RESULTS FOR ALCOA  
2091-T8X SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
<hr/>		
NORTHROP	L TRANS	43.0
		43.0
		43.2
	AVERAGE	43.1
	STANDARD DEVIATION	0.1

**TABLE K50**

**BEARING RESULTS FOR ALCOA**

**2091-T8X SHEET (0.144" X 48" X 48")**

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
NORTHROP	LONG	1.5		96.8		76.3
				92.9		73.6
		AVERAGE		94.9		75.0
		STANDARD DEVIATION		2.8		1.9

**TABLE K51**

**BEARING RESULTS FOR ALCOA**

**2091-T8X SHEET (0.063" X 48" X 48")**

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
NORTHROP	L TRANS	1.5		100.8		76.1
				99.3		75.1
				97.0		74.0
		AVERAGE		99.0		75.1
		STANDARD DEVIATION		1.9		1.1

**TABLE K52**  
**BEARING RESULTS FOR ALCOA**  
**2091-T8X SHEET (0.144" X 48" X 48")**

COMPANY	ORIENTATION	e/D	BEARING		BEARING
			ULT.	STR.	YIELD STR.
			(KSI)		(KSI)
NORTHROP	LONG	2.0		120.7	89.8
				122.4	89.1
				123.9	91.8
		AVERAGE	122.3	90.2	
		STANDARD DEVIATION	1.6	1.4	

**TABLE K53**  
**BEARING RESULTS FOR ALCOA**  
**2091-T8X SHEET (0.144" X 48" X 48")**

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
NORTHROP	L TRANS	2.0		125.6		91.9
				126.9		91.0
				126.1		94.6
		AVERAGE		126.2		92.5
		STANDARD DEVIATION		0.7		1.9

TABLE K54

R-CURVE FRACTURE TOUGHNESS RESULTS FOR  
ALCOA 2091-T8X SHEET (0.144" X 48" X 48")

COMPANY	SPECIMEN I.D.	ORIENTATION	K <sub>c</sub> (KSI SQRT-IN)
NORTHROP	T6RL1	L-T	135.0

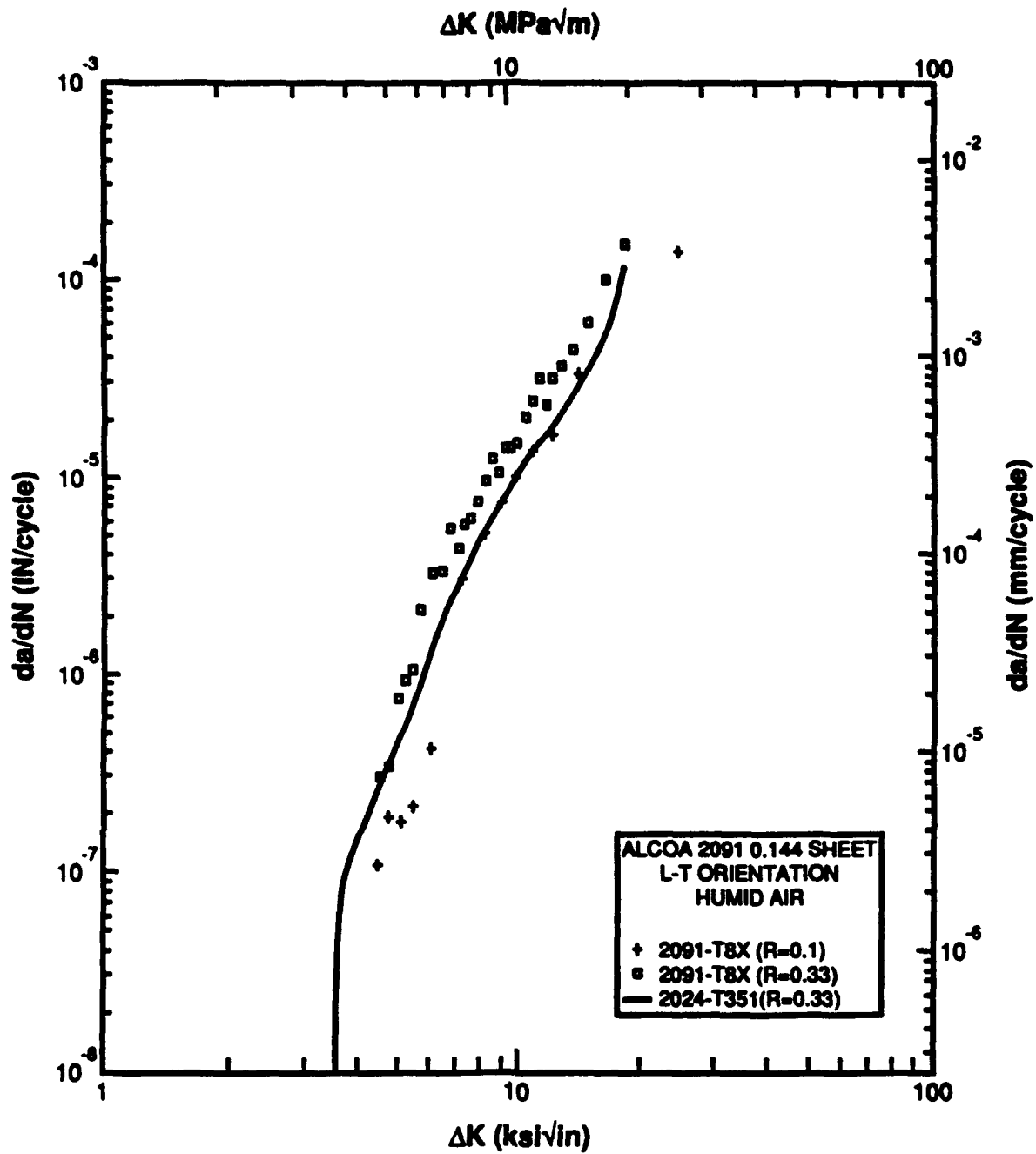


FIGURE K19. FATIGUE CRACK GROWTH RATES FOR 2091-T8X 0.144 INCH SHEET RELATIVE TO 2024-T351 (L-T ORIENTATION). NORTHROP.

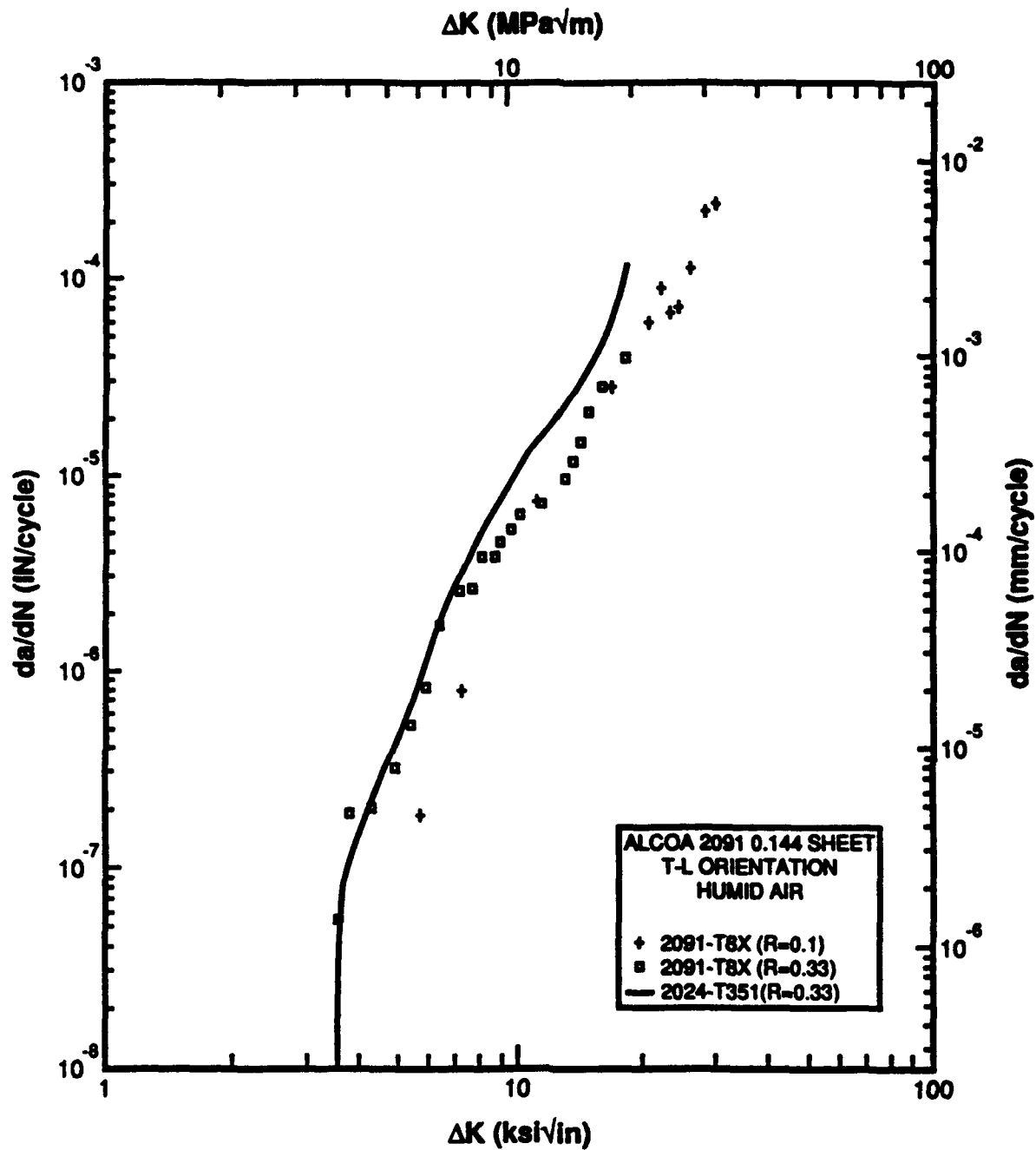


FIGURE K20. FATIGUE CRACK GROWTH RATES FOR 2091-T8X 0.144 INCH SHEET RELATIVE TO 2024-T351 (T-L ORIENTATION). NORTHROP.

## **APPENDIX L**

### **2091-T8 0.5 INCH PLATE**

#### **INTRODUCTION**

The Alcoa aluminum-lithium alloy 2091-T8 0.5 inch plates were received March 1988. The 2091-T8 0.5 inch plates were tested in the as received condition.

#### **TESTING**

Mechanical properties, (tension, compression, and fracture toughness) were tested according to ASTM standards, unless otherwise specified.

Over load fatigue crack growth tests were not performed according to ASTM standards.

**TABLE L1**  
**TENSILE RESULTS FOR ALCOA**  
**2091-T8 PLATE (0.5" X 48" X 48")**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
-----							
MARTIN MARIETTA, LOUISIANA	RT	LONG	74.8	62.1	11.0	11.4	
			74.2	61.4	11.0	10.8	
			75.2	62.3	10.0	11.4	
AIR FORCE	RT	LONG	76.2	64.0	8.9	16.2	
			75.6	63.4	9.4	17.0	
			75.3	62.8	8.6	15.1	
		AVERAGE	75.2	62.7	9.8	13.7	
		STANDARD DEVIATION	0.7	0.9	0.4	1.1	

**TABLE L2**  
**TENSILE RESULTS FOR ALCOA**  
**2091-T8 PLATE (0.5" X 48" X 48")**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	30	71.6	52.9	11.6	16.2	
			71.6	53.2	11.7	18.4	
		AVERAGE	71.6	53.1	11.7	17.3	
		STANDARD DEVIATION	0.0	0.2	0.1	1.5	

TABLE L3

## TENSILE RESULTS FOR ALCOA

2091-T8 PLATE (0.5" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)			
AIR FORCE	RT	45	64.0	46.6	19.4	32.9				
			63.6	45.9	19.1	35.5				
			63.6	45.9	19.6	33.6				
			AVERAGE			63.7	46.1	19.4	34.0	
			STANDARD DEVIATION			0.2	0.4	0.3	1.3	

TABLE L4

## TENSILE RESULTS FOR ALCOA

2091-T8 PLATE (0.5" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)			
MARTIN MARIETTA, LOUISIANA	RT	L TRANS	72.9	55.0	14.0	18.8				
			72.2	54.1	14.0	18.8				
			73.5	55.0	14.0	14.2				
AIR FORCE	RT	L TRANS	73.6	55.6	12.1	24.9				
			73.8	55.7	11.5	24.5				
			73.8	55.4	13.0	22.7				
			AVERAGE			73.3	55.1	13.1	20.7	
			STANDARD DEVIATION			0.6	0.6	1.1	4.1	

**TABLE L5**  
**COMPRESSION RESULTS FOR ALCOA**  
**2091-T8 PLATE (0.5" X 48" X 48")**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MARTIN	RT	LONG	52.2	11.8
MARIETTA,			51.4	11.8
LOUISIANA			52.4	11.8
		AVERAGE	52.0	11.8
		STANDARD DEVIATION	0.5	0.0

**TABLE L6**  
**COMPRESSION RESULTS FOR ALCOA**  
**2091-T8 PLATE (0.5" X 48" X 48")**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MARTIN	RT	L TRANS	57.9	11.9
MARIETTA,			58.8	11.9
LOUISIANA				
		AVERAGE	58.4	11.9
		STANDARD DEVIATION	0.6	0.0

TABLE L7  
FRACTURE TOUGHNESS RESULTS FOR ALCOA  
2091-T8 PLATE (0.5" X 48" X 48")

COMPANY	ORIENTATION	KIC	Kq	COMMENT
		(KSI in <sup>0.5</sup> )	(KSI in <sup>0.5</sup> )	
MARTIN	L - T		33.8	INVALID(1)
MARIETTA,			31.1	INVALID(1)
LOUISIANA			37.4	INVALID(1)
	AVERAGE		34.1	
	STANDARD DEVIATION		3.2	

(1): SPECIMEN SIZE TOO SMALL

TABLE L8  
FRACTURE TOUGHNESS RESULTS FOR ALCOA  
2091-T8 PLATE (0.5" X 48" X 48")

COMPANY	ORIENTATION	KIC	Kq	COMMENT
		(KSI in <sup>0.5</sup> )	(KSI in <sup>0.5</sup> )	
MARTIN	T - L		34.0	INVALID(1)
MARIETTA,			37.8	INVALID(1)
LOUISIANA			37.4	INVALID(1)
	AVERAGE		36.4	
	STANDARD DEVIATION		2.1	

(1): SPECIMEN SIZE TOO SMALL

TABLE L9  
POST-OVERLOAD FATIGUE TEST RESULTS for 2091-T8  
0.5 INCH PLATE and 2091-T83 0.144 INCH PLATE

**R=0.05 LAB AIR  $\Delta K=6.0 \text{ ksi}(\text{in})^{.5}$  ONE OVERLOAD CYCLE APPLIED**

<u>% O.L.</u>	<u>s/W</u>	<u>Pol/Pmax</u>	<u>da/dN @ O.L.</u> <u>(<math>\mu\text{-in/cyc}</math>)</u>	<u>DELAY CYCLES</u> <u>(<math>\times 10^{-3}</math>)</u>
PLATE SPECIMEN THICKNESS • 0.250"				
80	0.369	0.402	0.184	171.7
80	0.463	0.456	0.199	146.7
80	0.559	0.449	0.414	93.4
80	0.800	0.386	0.369	85.8
PLATE SPECIMEN THICKNESS • 0.140"				
80	0.401	0.845	0.097	arrest
80	0.447	0.803	0.095	arrest
60	0.407	0.535	0.135	137.8
60	0.415	0.640	0.076	arrest
60	0.484	0.584	0.057	891.0
60	0.502	0.647	0.149	126.7
60	0.541	0.600	0.140	72.8
60	0.654	0.523	0.120	59.0
60	0.896	0.574	0.107	71.5
SHEET SPECIMEN THICKNESS • 0.140"				
60	0.264	0.516	1.227	13.2
60	0.276	0.511	0.896	31.8
60	0.314	0.505	2.435	17.4
60	0.315	0.501	1.381	19.7
60	0.349	0.483	1.133	30.3
60	0.368	0.45	2.485	13.8
60	0.400	0.413	2.331	22.0
60	0.447	0.446	1.824	14.3
60	0.516	0.379	3.143	11.6
60	0.574	0.344	3.527	10.3

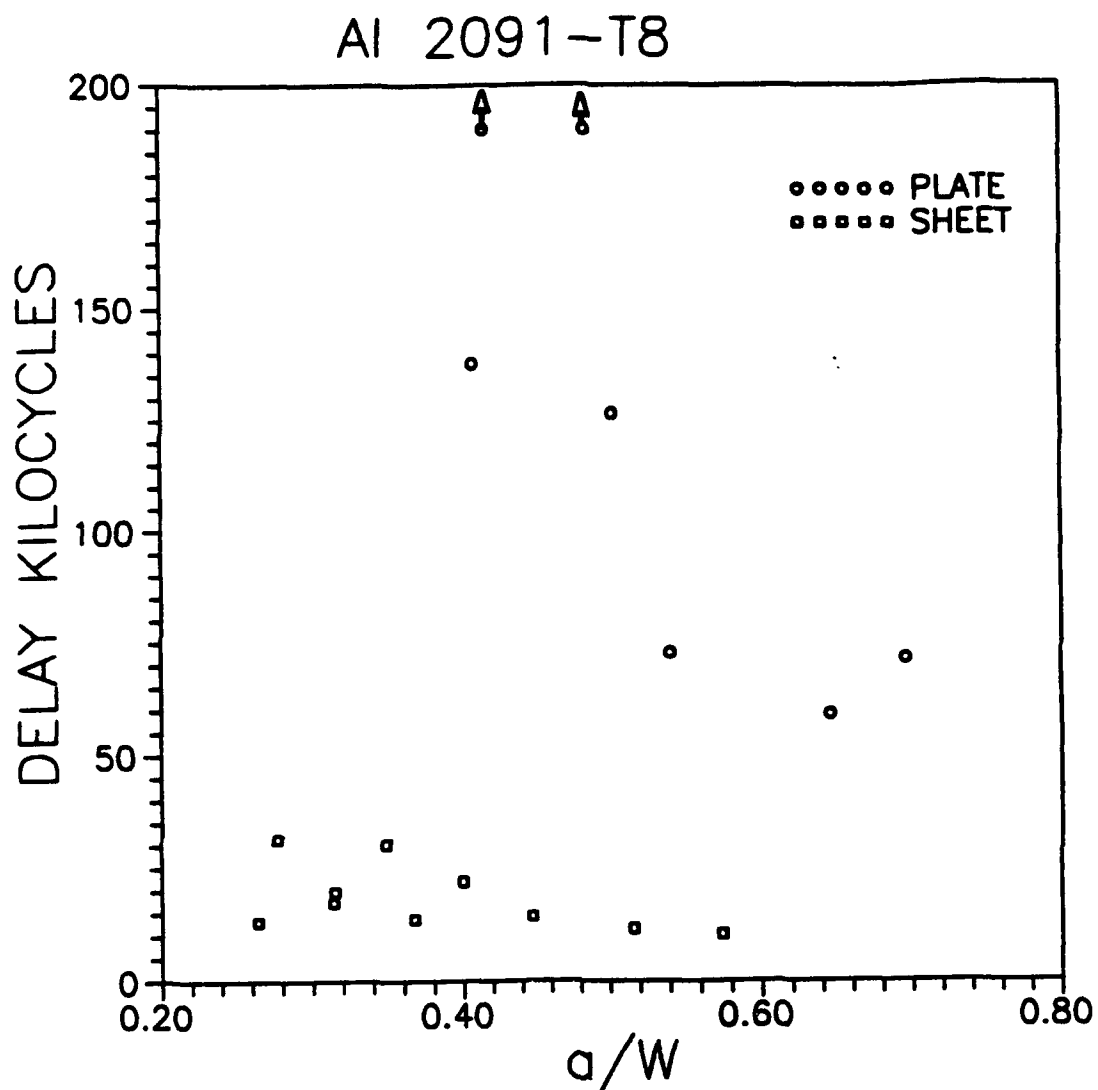


FIGURE L1. A Comparison of Delay Cycles Due to Fatigue Crack Growth Retardation for a 60 Percent Overload Cycle at a Stress Intensity of 6 KSI $\sqrt{\text{in}}$  in 2091-T81 Plate Versus 2091-T83 Sheet. Thickness of the Compact Tension Specimens Used for Plate and Sheet was 0.144 Inch. Air Force.

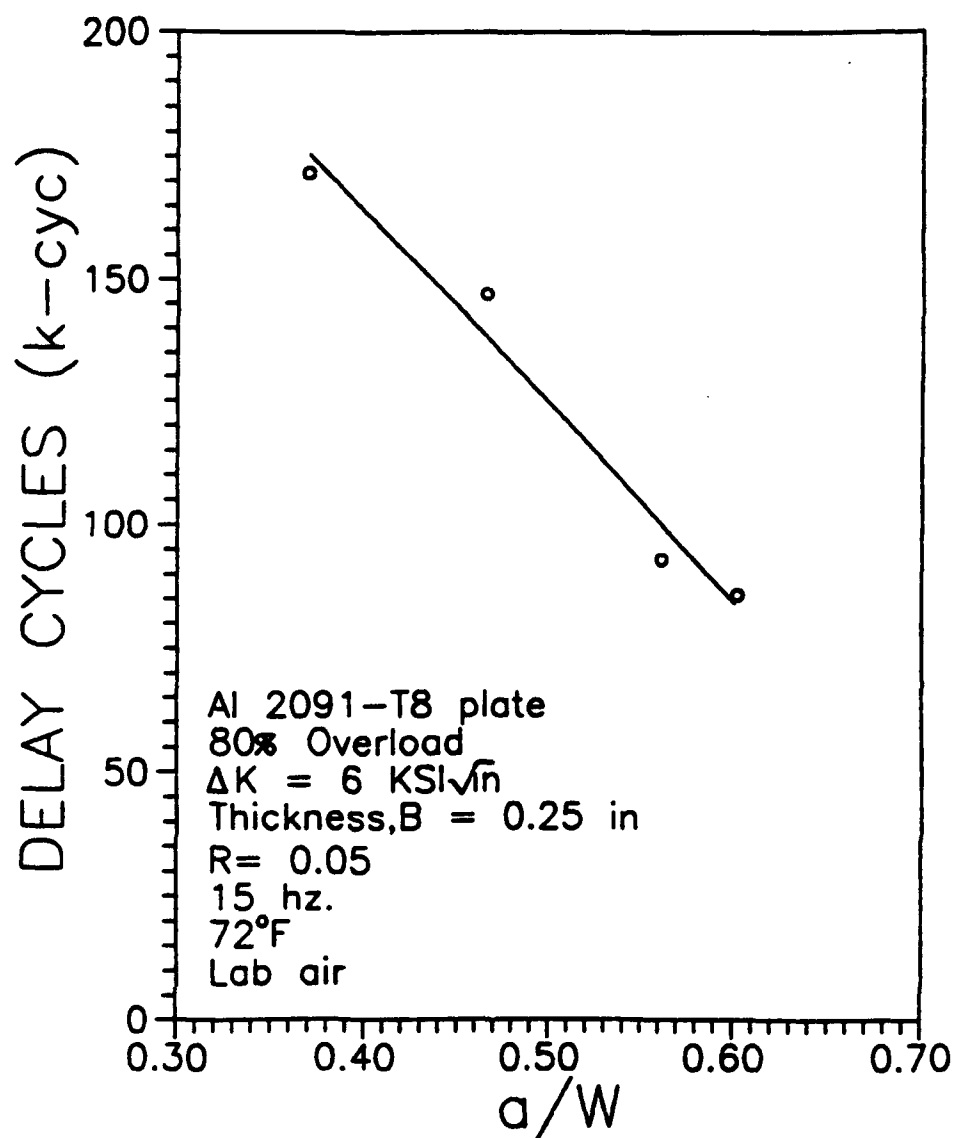


FIGURE L2. Delay Cycles Due to Fatigue Crack Growth Retardation for an 80 Percent Overload Cycle at a Stress Intensity Range of  $6 \text{ KSI}\sqrt{\text{in}}$ , in 2091-T81 Plate, with a Specimen Thickness of 0.250 Inch. Air Force.

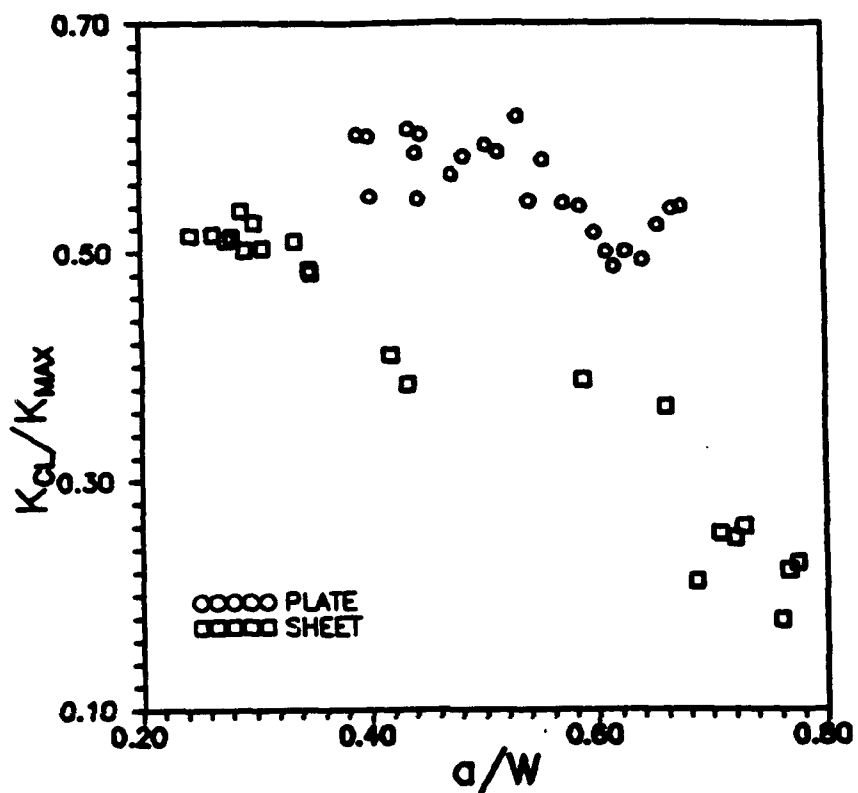


FIGURE L3. A Comparison of the Crack Closure Level Prior to the Application of a 60 Percent Overload Cycle. Note the Larger Level of Crack Closure in the Plate as Compared to Sheet Which Correlates with the Overload Delay Cycles. Air Force.

**TABLE L10**  
**POST-OVERLOAD RECOVERY EXTENSION**  
**IN 2091 PLATE AND SHEET**

<b>delta-K= 8.0 ksi(in)<sup>1/2</sup></b>		<b>One Overload Cycle Applied</b>	
<b>15 Hz.</b>	<b>Lab Air</b>	<b>R=.05</b>	<b>Crack Tip Plastic Zone=0.004 (in)</b>
<u>a/W</u>	<u>da/dN @ O.L.</u> <u>(in/cyc)</u>	<u>Accelerate into</u> <u>Plastic Zone?</u>	<u>Post O.L. Recovery</u> <u>delta-A (in)</u>
<b>PLATE (.250 in. thick)</b>			
<b>80 PERCENT OVERLOAD</b>			
0.389	0.184	Yes	0.020
0.463	0.199	Yes	0.025
0.559	0.414	Yes	0.025
0.600	0.399	Yes	0.015
<b>PLATE (.144 in. thick)</b>			
<b>80 PERCENT OVERLOAD</b>			
0.401	0.097	Yes	arrest
0.447	0.095	No	arrest
<b>PLATE (.144 in. thick)</b>			
<b>60 PERCENT OVERLOAD</b>			
0.407	0.135	No	0.015
0.415	0.078	No	arrest
0.484	0.057	No	0.024
0.502	0.149	No	0.016
0.541	0.140	No	0.015
0.654	0.120	No	0.009
0.696	0.107	Yes	0.016
<b>SHEET (.144 in. thick)</b>			
<b>60 PERCENT OVERLOAD</b>			
0.246	1.227	Yes	0.016
0.276	0.696	Yes	0.015
0.314	2.435	Yes	0.042
0.315	1.381	Yes	0.020
0.349	1.133	No	0.020
0.368	2.495	Yes	0.026
0.400	3.331	Yes	0.025
0.447	1.624	Yes	0.016
0.516	3.143	No	0.020
0.574	3.527	Yes	0.026

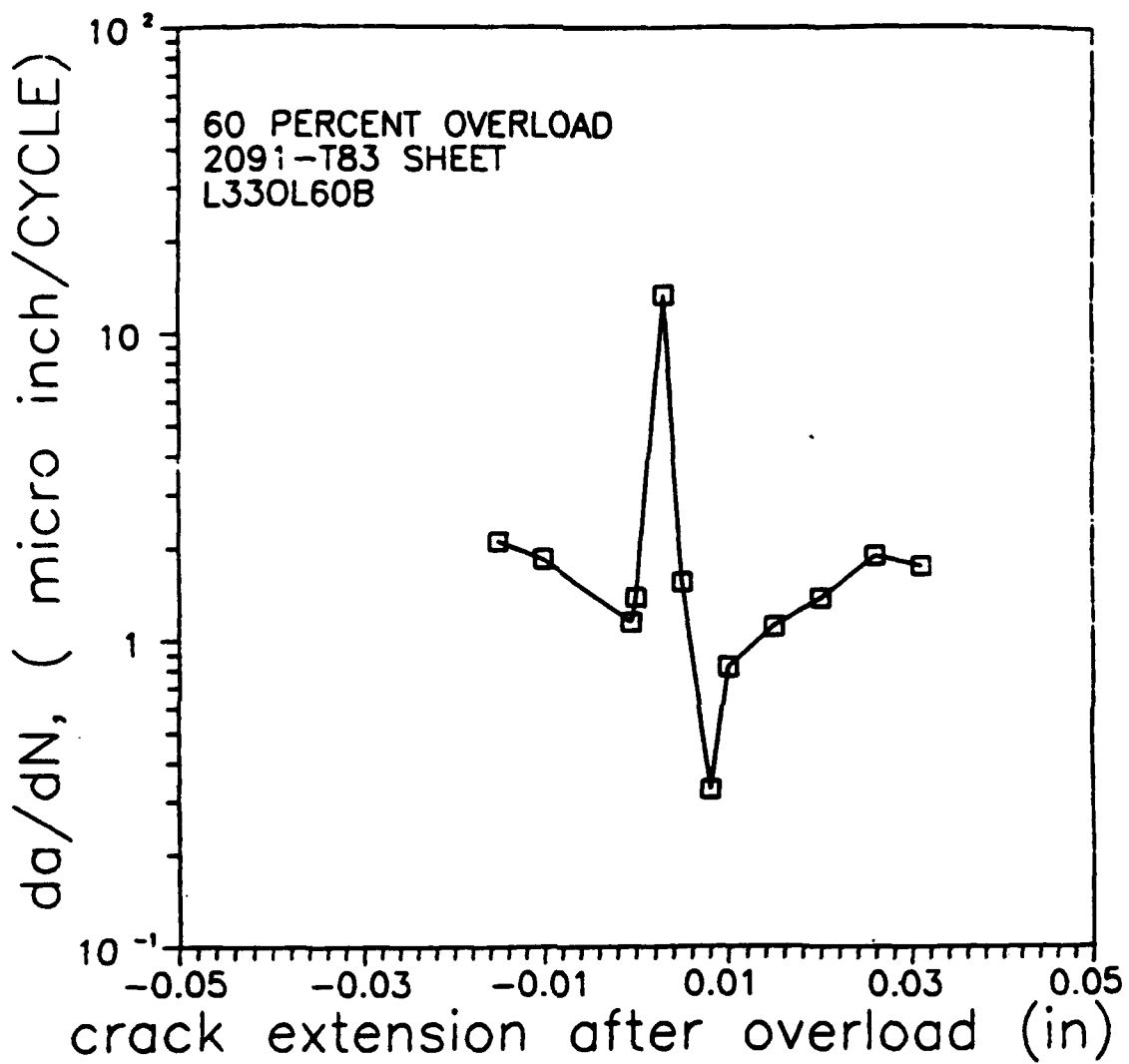


FIGURE L4. Crack Velocity Post-Overload Crack Extension  
for Alloy 2091-T83 Sheet.  
Air Force.

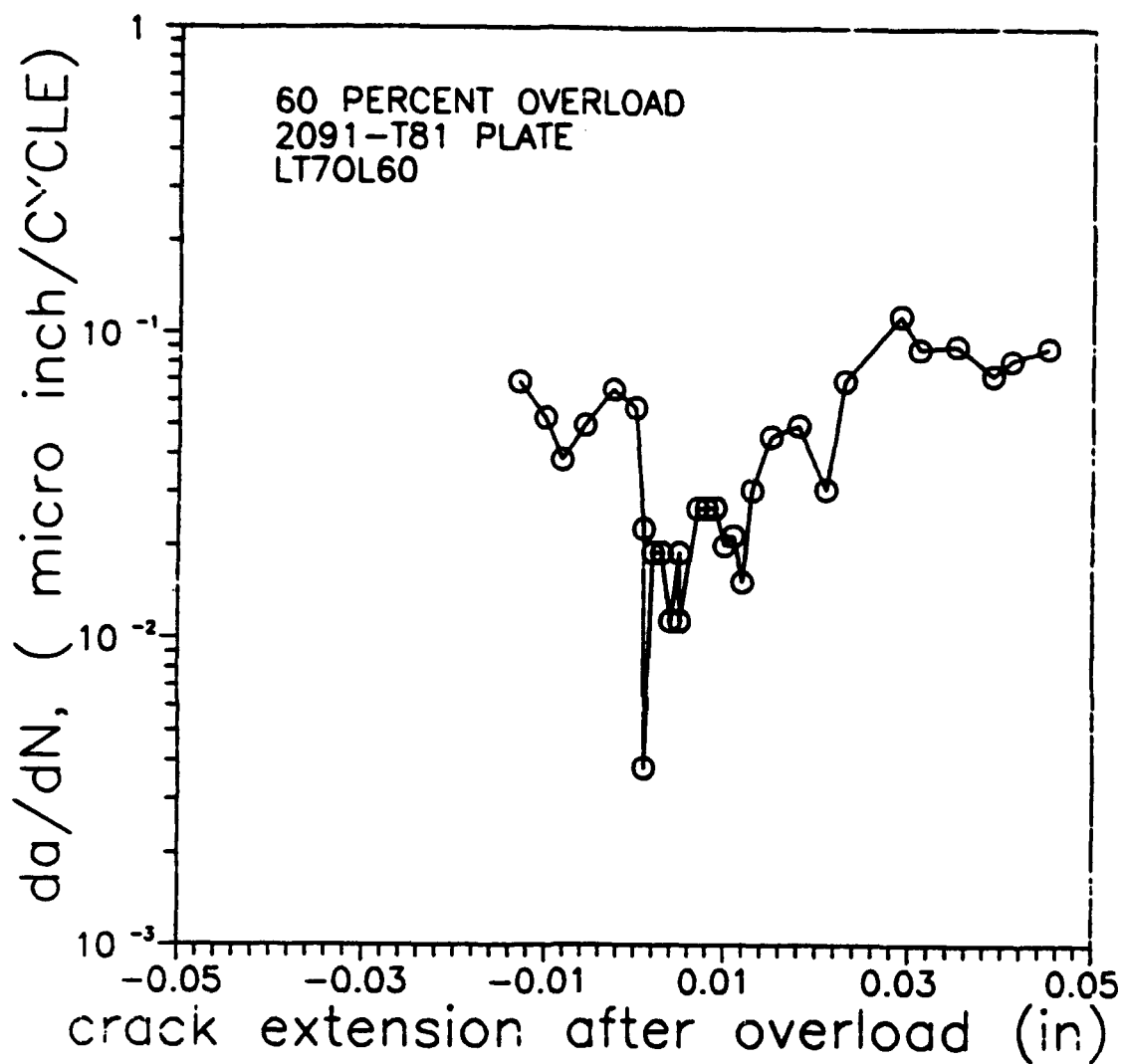


FIGURE L5. Crack Velocity Versus Post-Overload Crack Extension for Alloy 2091-T81 Plate 0.144 Inch Thick Specimen. Air Force.

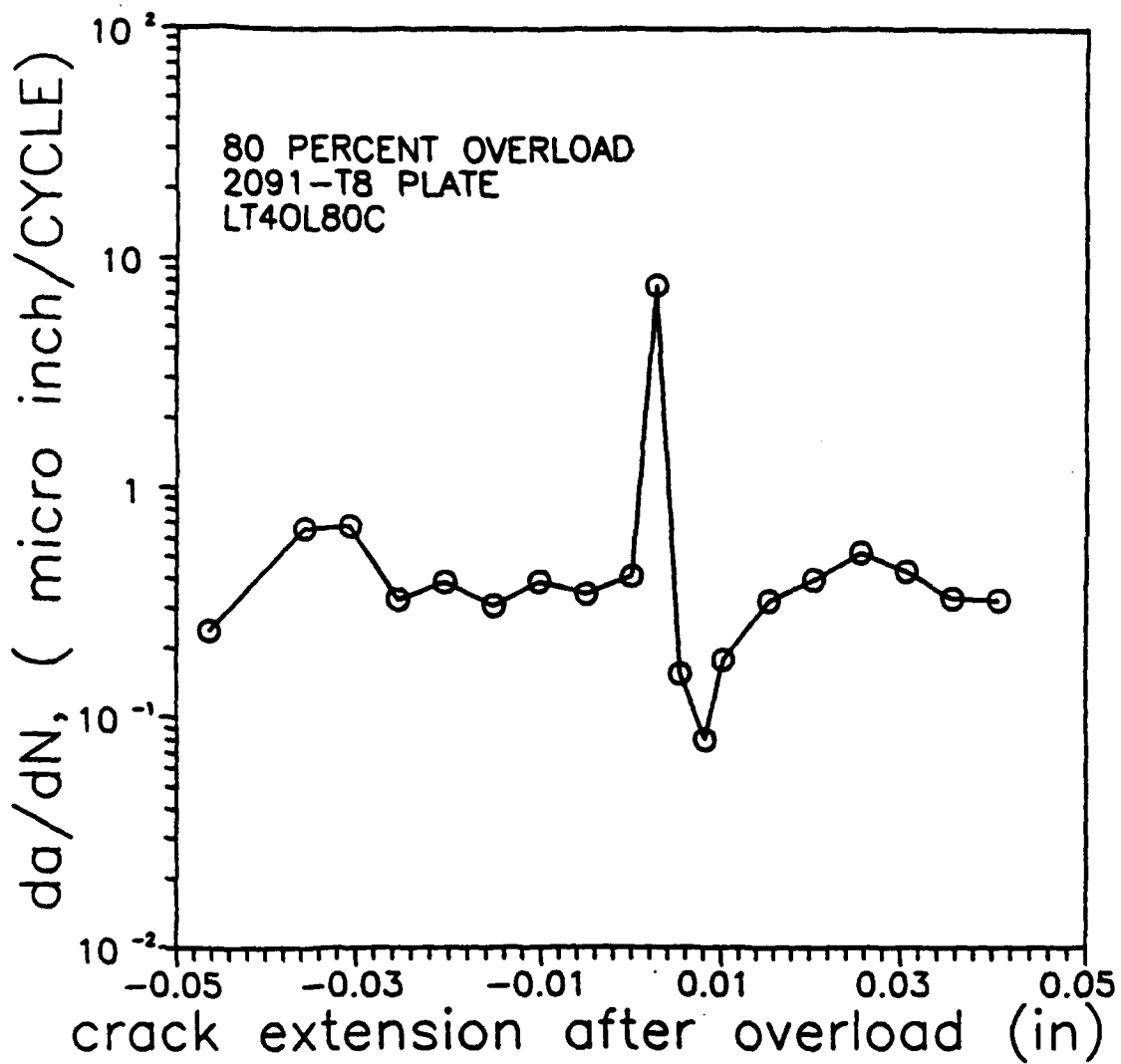


FIGURE L6. Crack Velocity Versus Post-Overload Crack Extension for Alloy 2091-T81 Plate 0.250 Inch Thick Specimen. Air Force.

## **APPENDIX M**

### **8090-T8 Hat Extrusion and 8090-T8771 L-Extrusion**

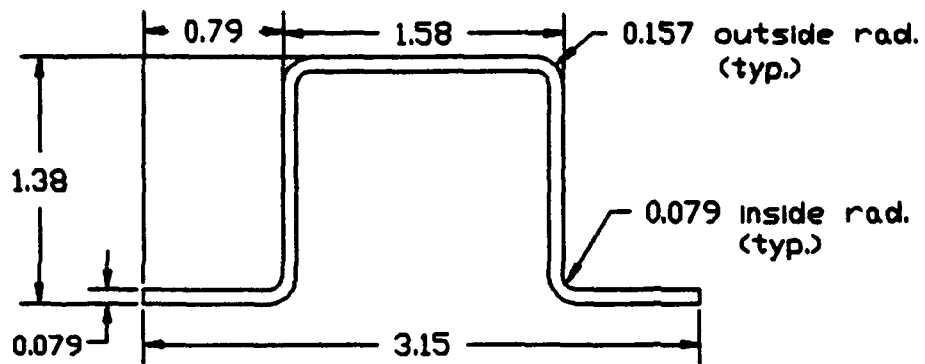
#### **INTRODUCTION**

The Alcoa 8090-T8 hat extrusions and 8090-T8 L-extrusions were received September 1991. The dimensions of the 8090-T8 hat and L-Extrusions are shown in Figure M1 and Figure M2 respectively. The L-extrusion had to be cut to achieve the T8 condition, therefore making a thin and a thick piece. The L-extrusion was received in two pieces (0.60" x 4.00" x length and 1.55" x 1.55" x length).

#### **TESTING**

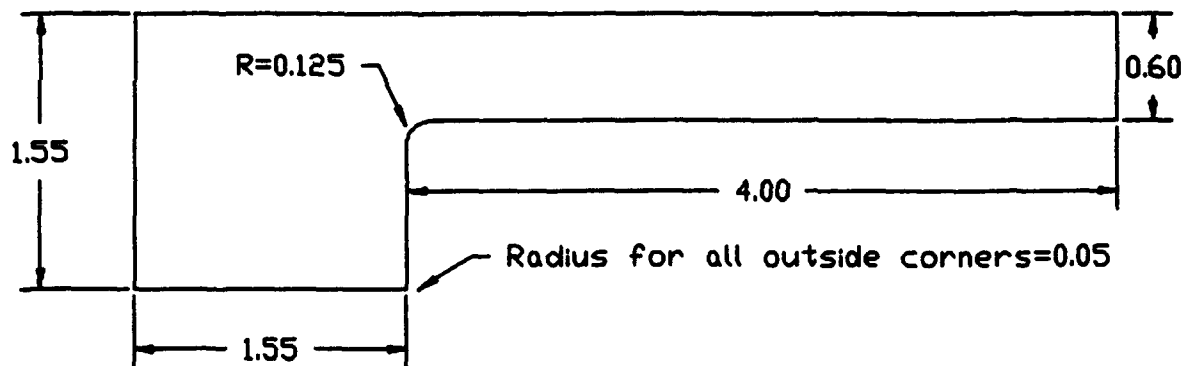
Mechanical properties, (tension, compression, bearing, shear, and fracture toughness) fatigue and constant amplitude fatigue crack growth tests were tested according to ASTM standards, unless otherwise specified.

Spectrum tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.



ALL DIMENSIONS ARE IN INCHES

FIGURE M1. 8090-T8 HAT EXTRUSION GEOMETRY.



ALL DIMENSIONS ARE IN INCHES

FIGURE M2. 8090-T8 L-EXTRUSION GEOMETRY.

**TABLE M1**  
**TENSILE RESULTS AT t/2 LOCATION FOR**  
**ALCOA 8090-T8 HAT EXTRUSION**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	COMMENT		
ARMY-MTL	RT	LONG	62.5	55.4	4.1	3.9	TOP		
			62.8	56.0	5.5	5.7	TOP		
			63.3	55.6	5.1	5.5	TOP		
			63.5	56.7	4.3	5.9	TOP		
			62.8	55.9	4.7	5.3	TOP		
			62.9	56.3	3.8	4.5	TOP		
			AVERAGE		62.9	56.0	4.6	5.1	
			STANDARD DEVIATION		0.4	0.4	0.6	0.8	

**TABLE M2**  
**TENSILE RESULTS AT t/2 LOCATION FOR**  
**ALCOA 8090-T8 HAT EXTRUSION**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	COMMENT		
ARMY-MTL	RT	LONG	64.1	56.6	4.5	4.1	BOTTOM		
			63.4	57.1	3.3	3.6	BOTTOM		
			64.3	54.7	5.0	5.3	BOTTOM		
			63.5	56.3	5.7	5.9	BOTTOM		
			63.1	55.9	3.5	4.2	BOTTOM		
			61.9	55.4	4.2	6.5	BOTTOM		
			AVERAGE			63.4	56.0	4.4	4.9
			STANDARD DEVIATION			0.9	0.9	0.9	1.1

TABLE M3  
TENSILE RESULTS AT t/2 LOCATION FOR  
ALCOA 8090-T8 HAT EXTRUSION

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	COMMENT		
ARMY-MTL	RT	LONG	64.0	55.7	5.6	5.8	SIDE		
			64.3	56.9	4.1	4.2	SIDE		
			64.1	57.0	4.8	5.7	SIDE		
			64.7	57.4	4.5	4.1	SIDE		
			65.2	57.8	5.5	3.7	SIDE		
			64.5	57.3	5.5	4.6	SIDE		
			AVERAGE			64.5	57.0	5.0	4.7
			STANDARD DEVIATION			0.4	0.7	0.6	0.9

**TABLE M4**  
**BEARING RESULTS FOR ALCOA**  
**8090-T8 HAT EXTRUSION**

COMPANY	ORIENTATION	e/D	BEARING		COMMENT		
			ULT. STR. (KSI)	YIELD STR. (KSI)			
ARMY-MTL	LONG	1.5	85.9	74.2	TOP		
			87.5	73.4	TOP		
			85.6	75.2	TOP		
			AVERAGE			86.3	74.3
			STANDARD DEVIATION			1.0	0.9

**TABLE M5**  
**BEARING RESULTS FOR ALCOA**  
**8090-T8 HAT EXTRUSION**

COMPANY	ORIENTATION	e/D	BEARING		COMMENT
			ULT. STR. (KSI)	YIELD STR. (KSI)	
-----					
ARMY-MTL	LONG	1.5	91.7	81.6	SIDE
			95.4	80.9	SIDE
			93.2	80.1	SIDE
AVERAGE			93.4	80.9	
STANDARD DEVIATION			1.9	0.7	

**TABLE M6**  
**BEARING RESULTS FOR ALCOA**  
**8090-T8 HAT EXTRUSION**

COMPANY	ORIENTATION	e/D	BEARING		BEARING	COMMENT
			ULT.	STR.	YIELD STR.	
			(KSI)		(KSI)	
ARMY-MTL	LONG	2.0		98.9	78.6	TOP
				104.0	82.5	TOP
				106.2	81.5	TOP
AVERAGE				103.0	80.9	
STANDARD DEVIATION				3.7	2.0	

**TABLE M7**  
**BEARING RESULTS FOR ALCOA**  
**8090-T8 HAT EXTRUSION**

COMPANY	ORIENTATION	e/D	BEARING		BEARING	COMMENT
			ULT.	STR.	YIELD STR.	
			(KSI)		(KSI)	
ARMY-MTL	LONG	2.0		116.3	89.0	SIDE
				111.6	89.0	SIDE
				112.9	89.9	SIDE
AVERAGE				113.6	89.3	
STANDARD DEVIATION				2.4	0.5	

TABLE M8

TENSILE RESULTS AT t/2 LOCATION FOR  
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
ARMY-MTL	RT	LONG	76.0	69.6	2.8		10.9
			68.8	57.5	3.2		11.0
			70.8	58.0	4.7		11.3
			69.8	58.0	5.2		11.1
			69.4	59.0	3.4		10.8
			69.4	58.0	4.1		11.3
MARTIN MARIETTA, LA	RT	LONG	72.1	64.9	5.0	4.9	(1)
			70.3	60.1	6.0	6.3	(1)
			70.4	59.6	5.0	3.3	(1)
			79.5	76.8	5.0	4.1	(2)
			79.5	76.3	3.0	3.9	(2)
			78.9	76.8	5.0	4.1	(2)
AVERAGE			73.0	64.8	4.6	4.4	11.1
STANDARD DEVIATION			4.4	8.4	0.9	1.0	0.2

(1): THICK SECTION

(2): THIN SECTION

TABLE M9

TENSILE RESULTS AT t/2 LOCATION FOR  
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
ARMY-MTL	RT	L TRANS	68.2	52.8	6.3		11.0
			68.4	53.8	5.0		10.8
			68.6	53.0	6.5		10.6
			68.0	52.5	6.5		10.3
			67.5	54.0	4.1		11.0
			68.5	53.5	5.9		10.8
MARTIN MARIETTA, LA	RT	L TRANS	69.9	55.1	8.0	11.0	(1)
			69.6	55.4	7.0	8.0	(1)
			70.0	55.2	8.5	9.0	(1)
		AVERAGE	68.7	53.9	6.4	9.3	10.8
		STANDARD DEVIATION	0.9	1.1	1.4	1.5	0.3

(1): THIN SECTION

TABLE M10

TENSILE RESULTS AT t/2 LOCATION FOR  
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
ARMY-MTL	RT	S TRANS	66.5	51.0	6.0		9.9
			58.3	43.0	8.0		9.6
			67.0	52.0	8.0		9.8
		AVERAGE	63.9	48.7	7.3		9.8
		STANDARD DEVIATION	4.9	4.9	1.2		0.2

TABLE M11

COMPRESSION RESULTS AT t/2 LOCATION FOR  
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
ARMY-MTL	RT	LONG	65.3	10.6
			54.6	10.4
			53.8	11.1
			61.7	9.9
			52.8	11.9
			53.9	10.8
MARTIN MARIETTA, LA	RT	LONG	49.8	11.5 (1)
			43.4	(1)
			50.0	11.9 (1)
			54.1	11.9 (2)
			47.9	11.8 (2)
			47.7	11.8 (2)
AVERAGE			52.9	11.2
STANDARD DEVIATION			6.0	0.7

(1): THICK SECTION  
(2): THIN SECTION

**TABLE M12**  
**COMPRESSION RESULTS AT t/2 LOCATION FOR**  
**ALCOA 8090-T8771 "L" EXTRUSION**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
-----				
ARMY-MTL	RT	L TRANS	58.2	9.5
			59.9	11.9
			58.8	13.4
			55.7	11.8
			58.1	11.3
			64.7	8.9
MARTIN MARIETTA, LA	RT	L TRANS	52.0	11.9 (1)
			49.8	11.7 (1)
			49.8	11.8 (1)
AVERAGE			56.3	11.4
STANDARD DEVIATION			5.0	1.4

(1): THICK SECTION

TABLE M13

COMPRESSION RESULTS AT t/2 LOCATION FOR  
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
ARMY-MTL	RT	S TRANS	51.5 52.0 52.0	10.1 11.2 11.5
MARTIN MARIETTA, LA	RT	S TRANS	50.1 50.2 50.1	11.7 (1) 11.8 (1) 11.4 (1)
		AVERAGE	51.0	11.3
		STANDARD DEVIATION	0.9	0.6

(1): THICK SECTION

**TABLE M14**

**RIVET SHEAR RESULTS FOR ALCOA  
8090-T8771 "L" EXTRUSION**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<hr/>		
<b>ARMY-MTL</b>	<b>LONG</b>	<b>40.7</b>
		<b>41.4</b>
		<b>45.0</b>
		<b>39.6</b>
		<b>41.4</b>
		<b>39.9</b>
	<b>AVERAGE</b>	<b>41.3</b>
	<b>STANDARD DEVIATION</b>	<b>2.3</b>

**TABLE M15**

**RIVET SHEAR RESULTS FOR ALCOA  
8090-T8771 "L" EXTRUSION**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<hr/>		
<b>ARMY-MTL</b>	<b>L TRANS</b>	<b>38.3</b>
		<b>37.5</b>
		<b>35.5</b>
		<b>38.7</b>
		<b>38.0</b>
		<b>36.8</b>
	<b>AVERAGE</b>	<b>37.5</b>
	<b>STANDARD DEVIATION</b>	<b>1.4</b>

TABLE M16

FRACTURE TOUGHNESS RESULTS FOR  
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	ORIENTATION	KIC	Kq	COMMENT
		(KSI in <sup>0.5</sup> )	(KSI in <sup>0.5</sup> )	
ARMY-MTL	L-T		31.9	(1)
			32.9	(1)
			30.2	(1)
			29.0	(1)
MARTIN MARIETTA, LA	L-T		33.1	(1)
			38.5	(1)
		36.3		
	AVERAGE	36.3	32.6	
	STANDARD DEVIATION		3.3	

(1): INVALID DUE TO  $B < 2.5(KQ/Fty)^2$

TABLE M17

FRACTURE TOUGHNESS RESULTS FOR  
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	ORIENTATION	KIC (KSI in <sup>-0.5</sup> )	Kq (KSI in <sup>-0.5</sup> )	COMMENT
ARMY-MTL	T-L		29.8	(1), (2)
			28.9	(1), (2)
			30.8	(1), (2)
			30.2	(1), (2)
			30.9	(1), (2)
MARTIN MARIETTA, LA	T-L	20.2		
		19.7		
		18.0		
	AVERAGE	19.3	30.1	
	STANDARD DEVIATION	1.2	0.8	

(1): INVALID DUE TO  $P_{max}/P_q > 1.10$

(2): INVALID DUE TO  $B < 2.5(KQ/F_{ty})^2$

TABLE M18

**FRACTURE TOUGHNESS RESULTS FOR  
ALCOA 8090-T8771 "L" EXTRUSION**

COMPANY	ORIENTATION	KIC (KSI in <sup>0.5</sup> )	Kq (KSI in <sup>0.5</sup> )	COMMENT
<hr/>				
ARMY-MTL	S-L	22.6		
		22.6		
		22.7		
		22.4		
		22.3		
		21.5		
	AVERAGE	22.4		
	STANDARD DEVIATION	0.4		

TABLE M19

**FRACTURE TOUGHNESS RESULTS FOR  
ALCOA 8090-T8771 "L" EXTRUSION**

COMPANY	ORIENTATION	KIC (KSI in <sup>0.5</sup> )	Kq (KSI in <sup>0.5</sup> )	COMMENT
<hr/>				
MARTIN	S-T		19.2	(1)
MARIETTA, LA			21.7	(1)
		20.9		
	AVERAGE	20.9	20.5	
	STANDARD DEVIATION		1.8	

(1): INVALID DUE TO  $P_{max}/P_q > 1.10$

TABLE M20

FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR  
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
-----			
ARMY-MTL	LONG	47.5	30,000
		39.3	164,000
		30.1	1,411,000
		28.0	3,639,000
		27.8	171,000
		27.5	11,787,000 *
		26.2	10,382,000 *

(\*): RUN OUT

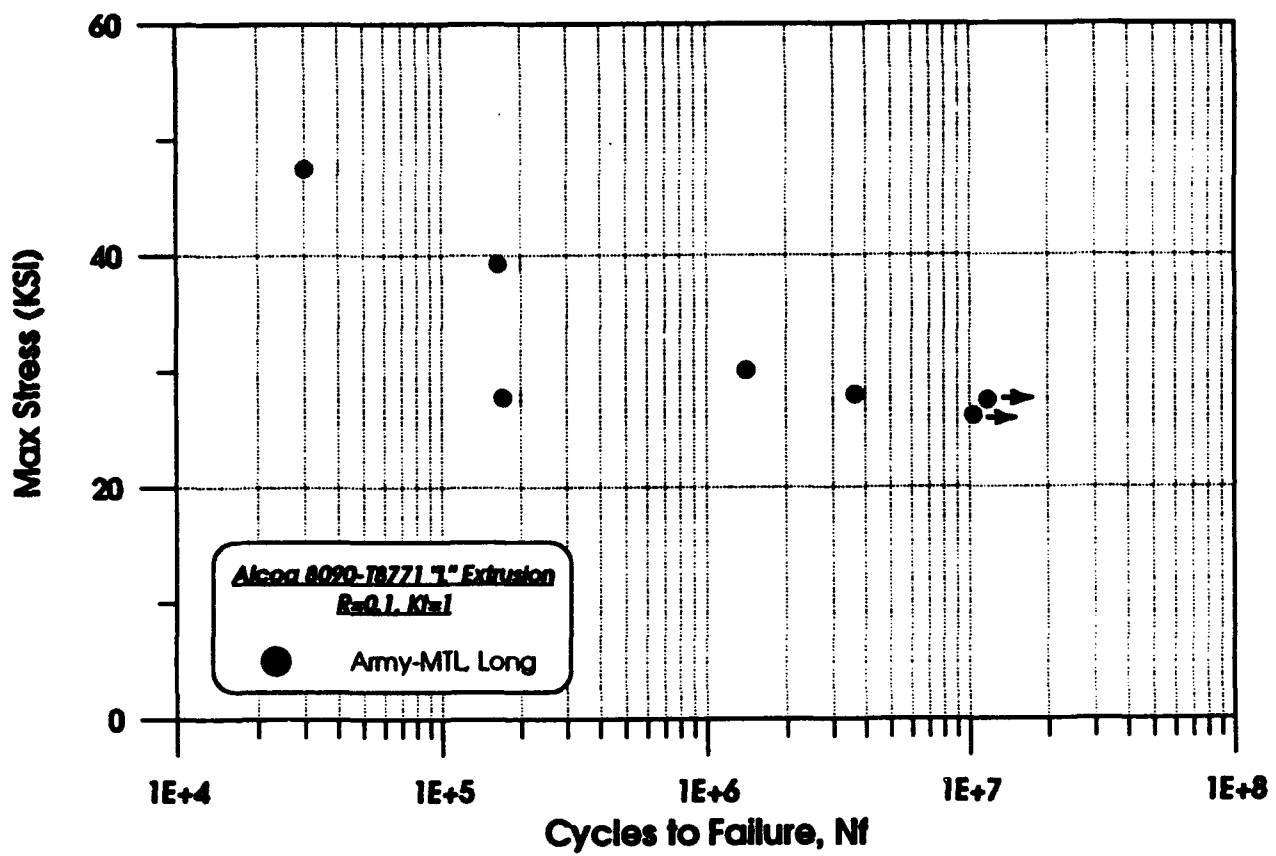
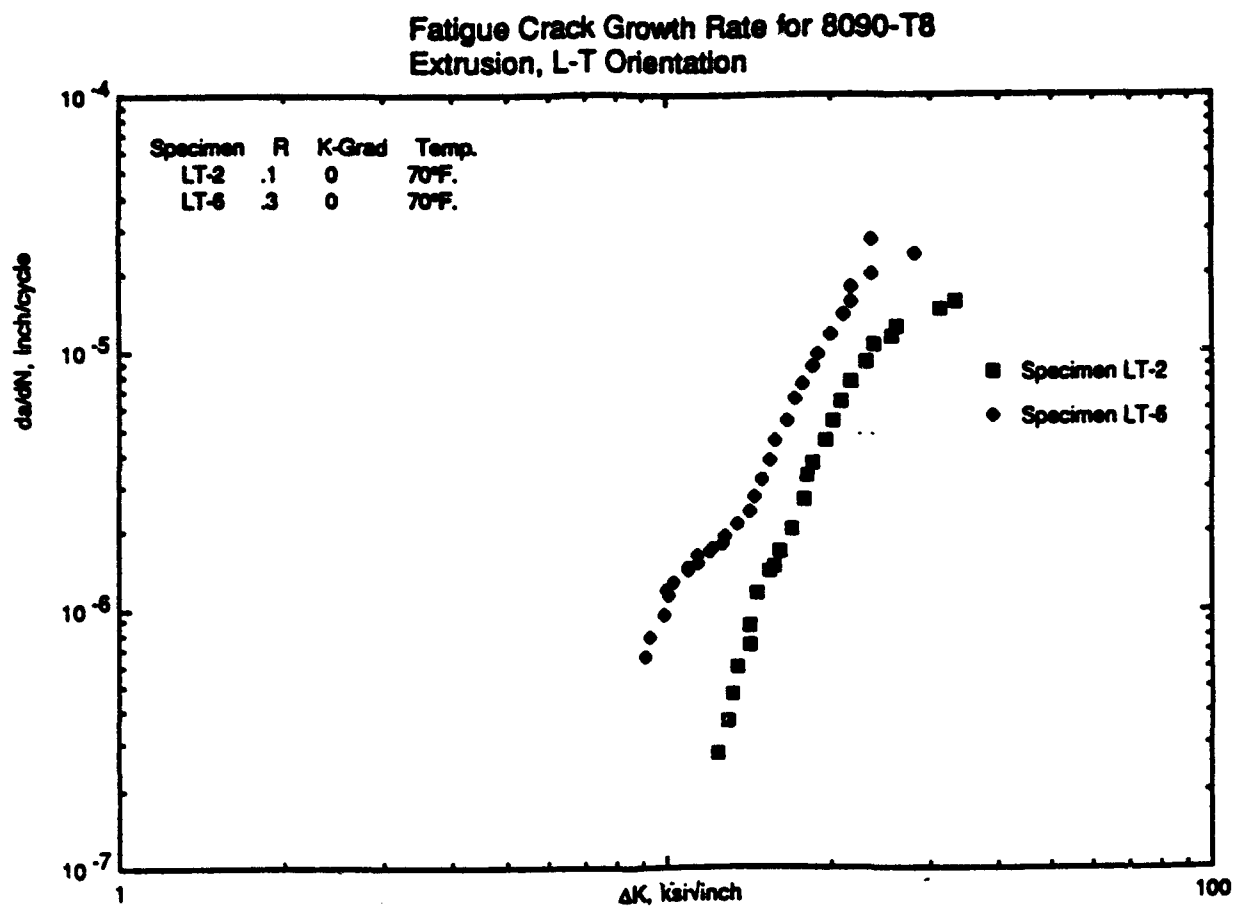


FIGURE M3. FATIGUE RESULTS FOR 8090-T8 771 L-EXTRUSION ( $R=0.1$  AND  $K_t=1.0$ ). Army.



**FIGURE M4. FATIGUE CRACK GROWTH RATES for  
8090-T8771 L-Extrusion (L-T Orientation).  
Martin Marietta.**

# Fatigue Crack Growth Rate for 8090-T8 Extrusion, T-L Orientation

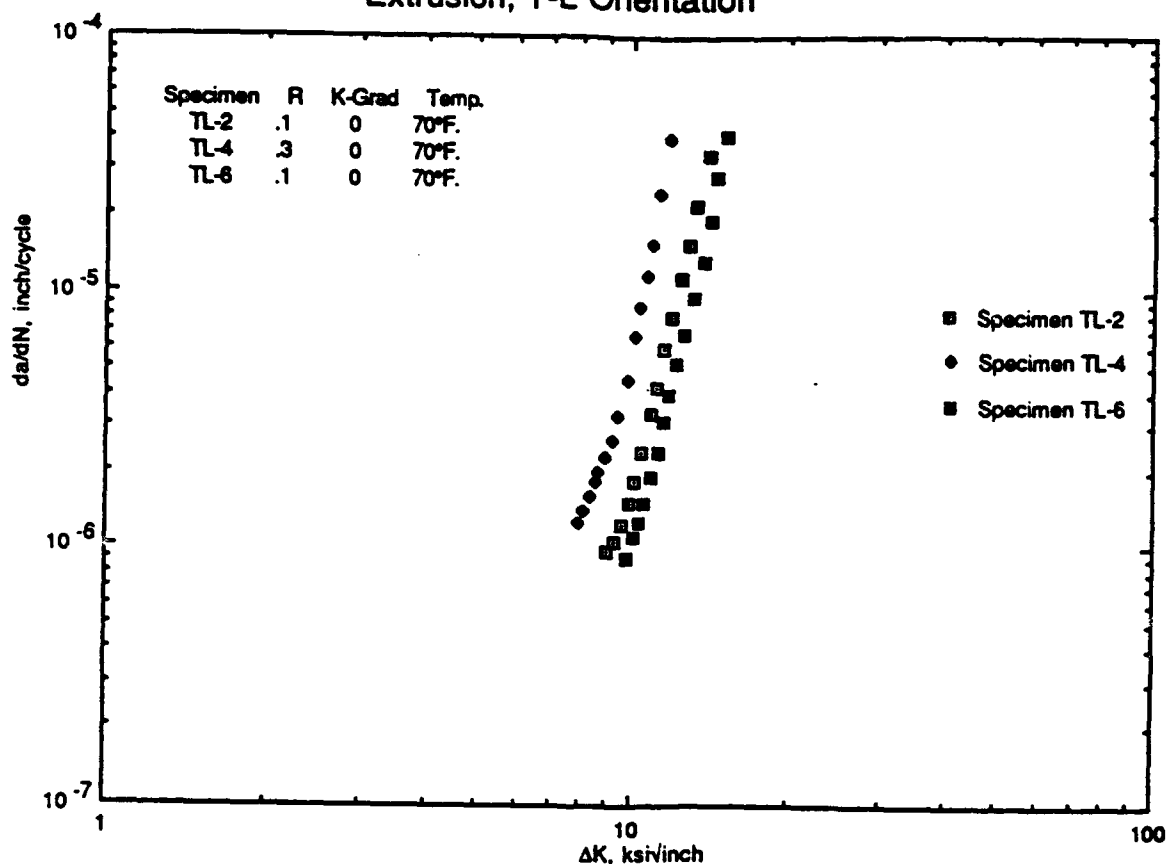
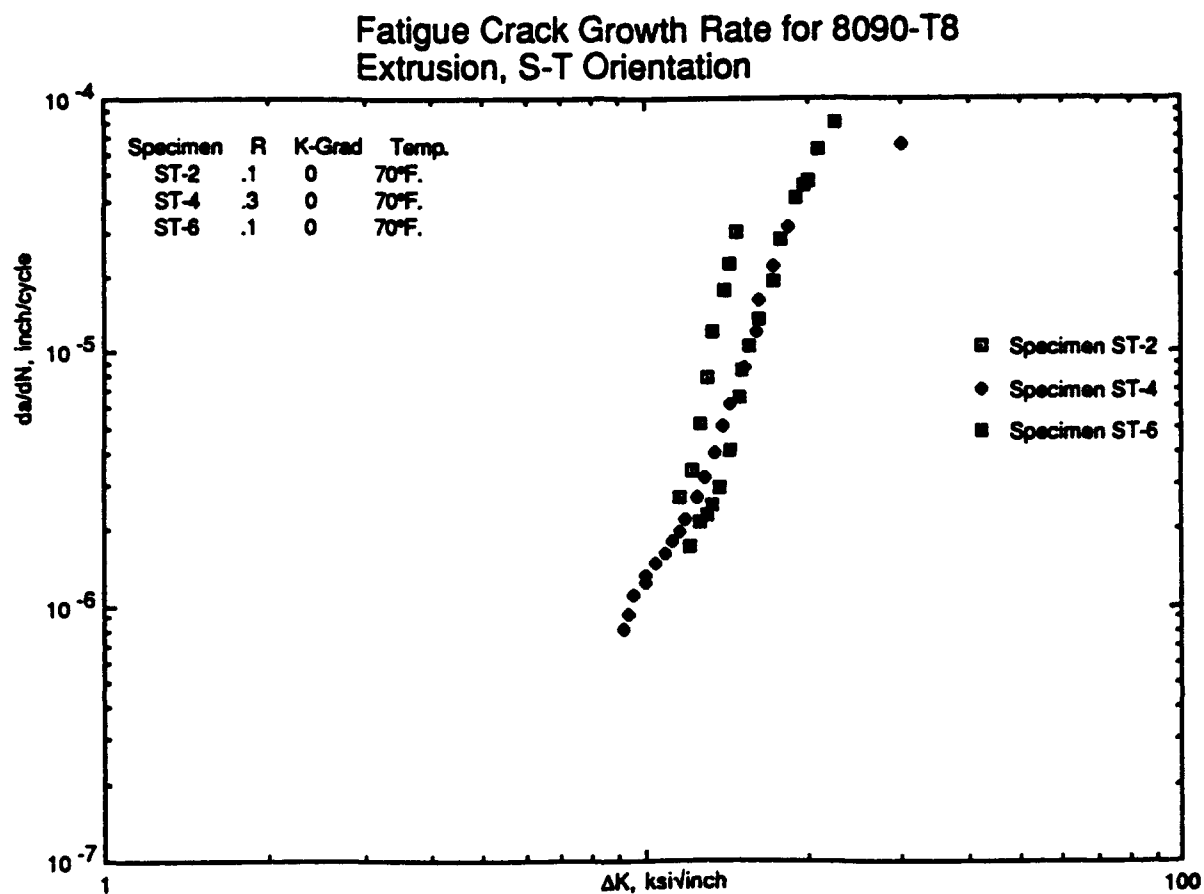


FIGURE M5. FATIGUE CRACK GROWTH RATES for  
8090-T8771 L-EXTRUSION  
(T-L Orientation).  
MARTIN MARIETTA.



**FIGURE M6. FATIGUE CRACK GROWTH RATES for  
8090-T8771 L-EXTRUSION  
(S-T Orientation).  
MARTIN MARIETTA.**

## **APPENDIX N**

### **7064-T74511 EXTRUSION 1"X4"X48"**

#### **INTRODUCTION**

The Kaiser P/M aluminum alloy 7064-T74511 1"x4"x48" extrusions were received in December 1986. The 7064 extrusions were tested by LTV, Martin Marietta and the Air Force.

#### **TESTING**

Mechanical properties (tension, compression, shear, bearing and fracture toughness), fatigue, and constant amplitude fatigue crack growth tests were generated according to ASTM standards, unless otherwise specified.

Spectrum fatigue crack growth rate tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

**TABLE N1**  
**TENSILE RESULTS AT t/2 LOCATION FOR**  
**KAISER 7064-T74511 EXTRUSION**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)
LTV	RT	LONG	85.8	79.4	12.2	21.6	10.0
			87.5	81.7	12.3	19.3	9.7
			87.7	82.2	14.3	22.3	10.3
AIR FORCE	RT	LONG	82.2	75.8	10.5	18.0	
			80.7	73.9	11.3	24.3	
			81.2	74.7	12.0	25.6	
MARTIN MARIETTA, LOUISIANA	RT	LONG	91.6	86.5	18.0	27.5	9.8
			90.5	85.3	20.0	30.6	9.4
			90.2	85.0	19.0	31.0	9.7
AVERAGE			86.4	80.5	14.4	24.5	9.8
STANDARD DEVIATION			4.2	4.8	3.6	4.6	0.3

**TABLE N2**  
**TENSILE RESULTS AT t/2 LOCATION FOR**  
**KAISER 7064-T74511 EXTRUSION**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)
LTV	RT	L TRANS	83.0	76.6	9.0	11.8	9.2
			85.3	79.6	8.5	19.1	10.4
			85.5	80.2	11.0	22.7	10.4
AIR FORCE	RT	L TRANS	79.2	72.8	10.0	21.6	
			78.3	72.0	10.7	25.6	
			79.1	72.6	11.3	27.8	
MARTIN MARIETTA, LOUISIANA	RT	L TRANS	88.8	82.7	8.0	7.8	10.7
			89.2	83.2	9.0	2.0	10.1
			88.0	82.7	10.0	16.1	9.7
AVERAGE			84.0	78.0	9.7	17.2	10.1
STANDARD DEVIATION			4.3	4.6	1.2	8.6	0.5

TABLE N3  
COMPRESSION RESULTS AT t/2 LOCATION FOR  
KAISER 7064-T74511 EXTRUSION

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
LTV	RT	LONG	97.4	14.8
			79.8	10.3
			83.0	11.8
AIR FORCE	RT	LONG	83.3	
			81.6	
			82.5	
MARTIN MARIETTA, LOUISIANA	RT	LONG	87.1	11.1
			86.0	11.1
			86.9	11.1
AVERAGE			85.3	11.7
STANDARD DEVIATION			5.2	1.6

TABLE N4  
COMPRESSION RESULTS AT t/2 LOCATION FOR  
KAISER 7064-T74511 EXTRUSION

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
LTV	RT	L TRANS	82.7	10.8
			82.9	11.8
			82.8	11.2
AIR FORCE	RT	L TRANS	83.3	
			81.8	
			84.1	
MARTIN MARIETTA, LOUISIANA	RT	L TRANS	87.3	11.4
			86.1	11.3
			86.6	11.9
AVERAGE			84.2	11.4
STANDARD DEVIATION			2.0	0.4

TABLE N5  
IOSIPESCU SHEAR RESULTS FOR  
KAISER 7064-T74511 EXTRUSION

COMPANY	ORIENTATION	ULTIMATE STRENGTH (KSI)
LTV	LONG	49.7
		51.0
		50.9
	AVERAGE	50.5
	STANDARD DEVIATION	0.7

TABLE N6  
IOSIPESCU SHEAR RESULTS FOR  
KAISER 7064-T74511 EXTRUSION

COMPANY	ORIENTATION	ULTIMATE STRENGTH (KSI)
LTV	L TRANS	50.4
		49.8
		50.2
	AVERAGE	50.1
	STANDARD DEVIATION	0.3

TABLE N7  
BEARING RESULTS FOR KAISER  
7064-T74511 EXTRUSION

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
LTV	LONG	1.5	124.5	93.9
			134.4	111.9
			129.8	108.2
		AVERAGE	129.6	104.7
		STANDARD DEVIATION	5.0	9.5

**TABLE N8**  
**BEARING RESULTS FOR KAISER**  
**7064-T74511 EXTRUSION**

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
LTV	LONG	2.0	159.5 169.5 160.8	122.7 122.2 117.0
AIR FORCE	LONG	2.0	163.5 166.7 162.3	139.5 125.3 120.0
		AVERAGE	163.7	124.5
		STANDARD DEVIATION	3.8	7.9

**TABLE N9**  
**BEARING RESULTS FOR KAISER**  
**7064-T74511 EXTRUSION**

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
AIR FORCE	L TRANS	2.0	164.2 159.3 163.5	123.8 114.7 115.6
		AVERAGE	162.3	118.0
		STANDARD DEVIATION	2.7	5.0

**TABLE N10**  
**FRACTURE TOUGHNESS RESULTS FOR**  
**KAISER 7064-T74511 EXTRUSION**

COMPANY	ORIENTATION	KIC		Kq	COMMENT
		(KSI IN <sup>0.5</sup> )	(KSI IN <sup>0.5</sup> )		
LTV	L-T			32.6	(1)
				33.5	(1)
				29.6	(1)
AIR FORCE	L-T			29.5	(2)
				27.9	(2)
				28.8	(2)
MARTIN MARIETTA, LOUISIANA	L-T	24.2			VALID
				26.3	(3)
				25.2	(3)
	AVERAGE	24.2		29.2	
	STANDARD DEVIATION			2.8	

(1): INVALID DUE TO TEST SPECIMEN FRACTURE SURFACE  
 VIOLATED KIC REQUIREMENTS

(2): INVALID DUE TO SURFACE CRACK LENGTH/AVERAGE CRACK LENGTH > 1.1

(3): INVALID DUE TO CRACK SIZE DID NOT EXCEED PLASTIC ZONE SIZE

**TABLE N11**  
**FRACTURE TOUGHNESS RESULTS FOR**  
**KAISER 7064-T74511 EXTRUSION**

COMPANY	ORIENTATION	KIC	K <sub>q</sub>	COMMENT
		(KSI IN <sup>-0.5</sup> )	(KSI IN <sup>-0.5</sup> )	
LTV	T-L	24.6		VALID
		25.0		VALID
		25.2		VALID
AIR FORCE	T-L	23.5		VALID
		24.1		VALID
		23.8		VALID
MARTIN MARIETTA, LOUISIANA	T-L		10.2	(1)
		17.1		
		17.1		
	AVERAGE	22.6	10.2	
	STANDARD DEVIATION	3.4		

(1): INVALID DUE TO PRECRACKING LOADS WERE TOO HIGH

**TABLE N12**  
**FATIGUE RESULTS WITH  $K_t=1.0$  AND  $R=0.1$  FOR**  
**KAISER 7064-T74511 EXTRUSION**

COMPANY	ORIENTATION	LIMIT STRESS (KSI)	CYCLES TO FAILURE
<hr/>			
LTV	LONG	65.6	13,900
		65.0	1,800
		56.6	23,400
		47.9	49,900
		47.9	75,700
		47.8	318,100 #
		45.0	6,500
		43.5	2,000,000 *
		39.4	38,500
		39.1	93,100 #
		37.0	193,900
		35.0	113,000
		30.0	800,000 *
		25.2	2,300,000 *

(\*): INDICATES A RUN OUT TEST

(#): INDICATES SPECIMEN FAILED IN THE THREADS

**TABLE N13**  
**FATIGUE RESULTS WITH  $K_t=3.0$  AND  $R=0.1$  FOR**  
**KAISER 7064-T74511 EXTRUSION**

COMPANY	ORIENTATION	LIMIT STRESS (KSI)	CYCLES TO FAILURE
<hr/>			
LTV	LONG	43.5	5,100
		34.8	10,800
		32.6	19,700
		31.3	23,500
		30.5	66,200
		28.3	39,300
		26.1	56,700
		26.1	40,400
		24.4	72,000
		23.9	3,000,000 *
		23.5	1,998,100
		21.8	2,000,000 *
		21.7	3,000,000 *
		20.0	2,000,000 *
		17.4	3,000,000 *

(\*): INDICATES A RUN-OUT TEST

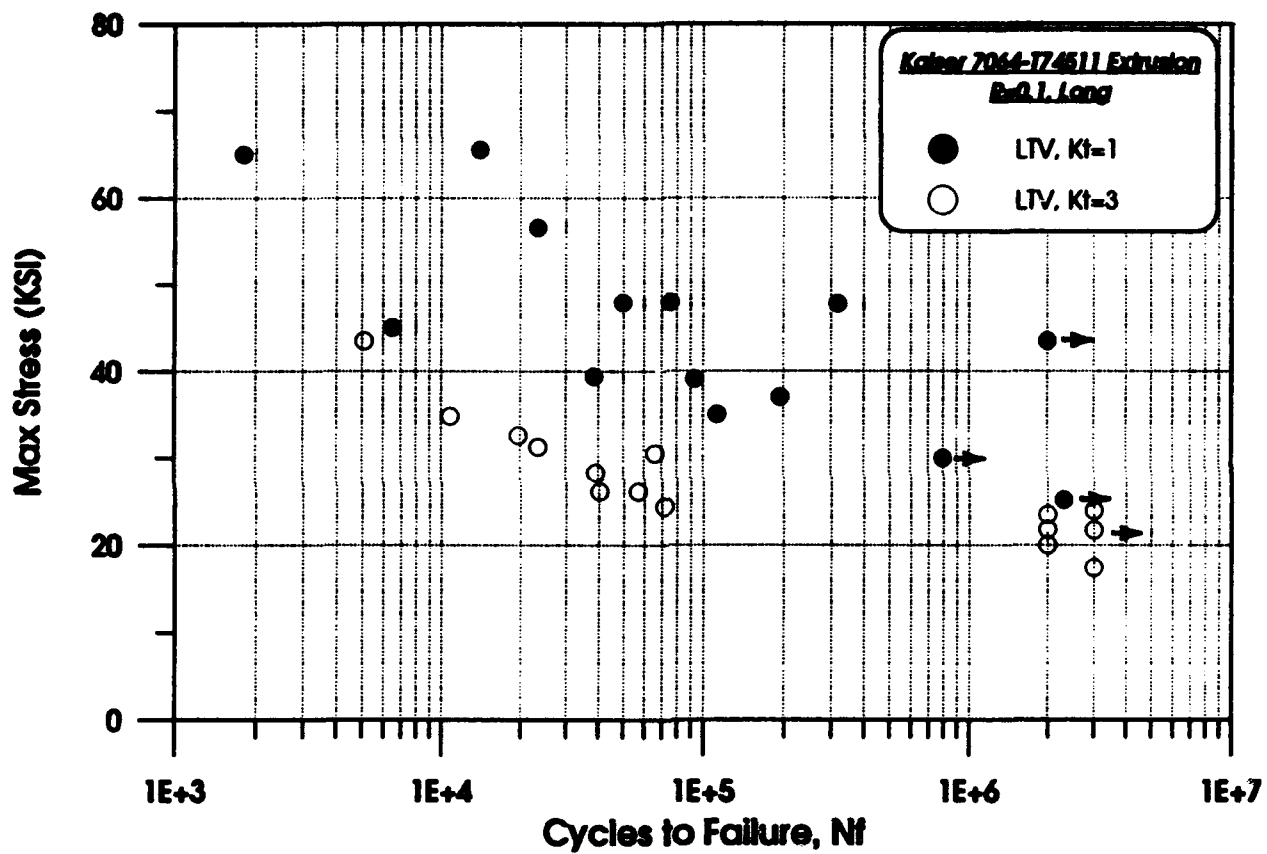


FIGURE N1. FATIGUE RESULTS FOR 7064-T74511 EXTRUSION (LONGITUDINAL ORIENTATION). LTV.

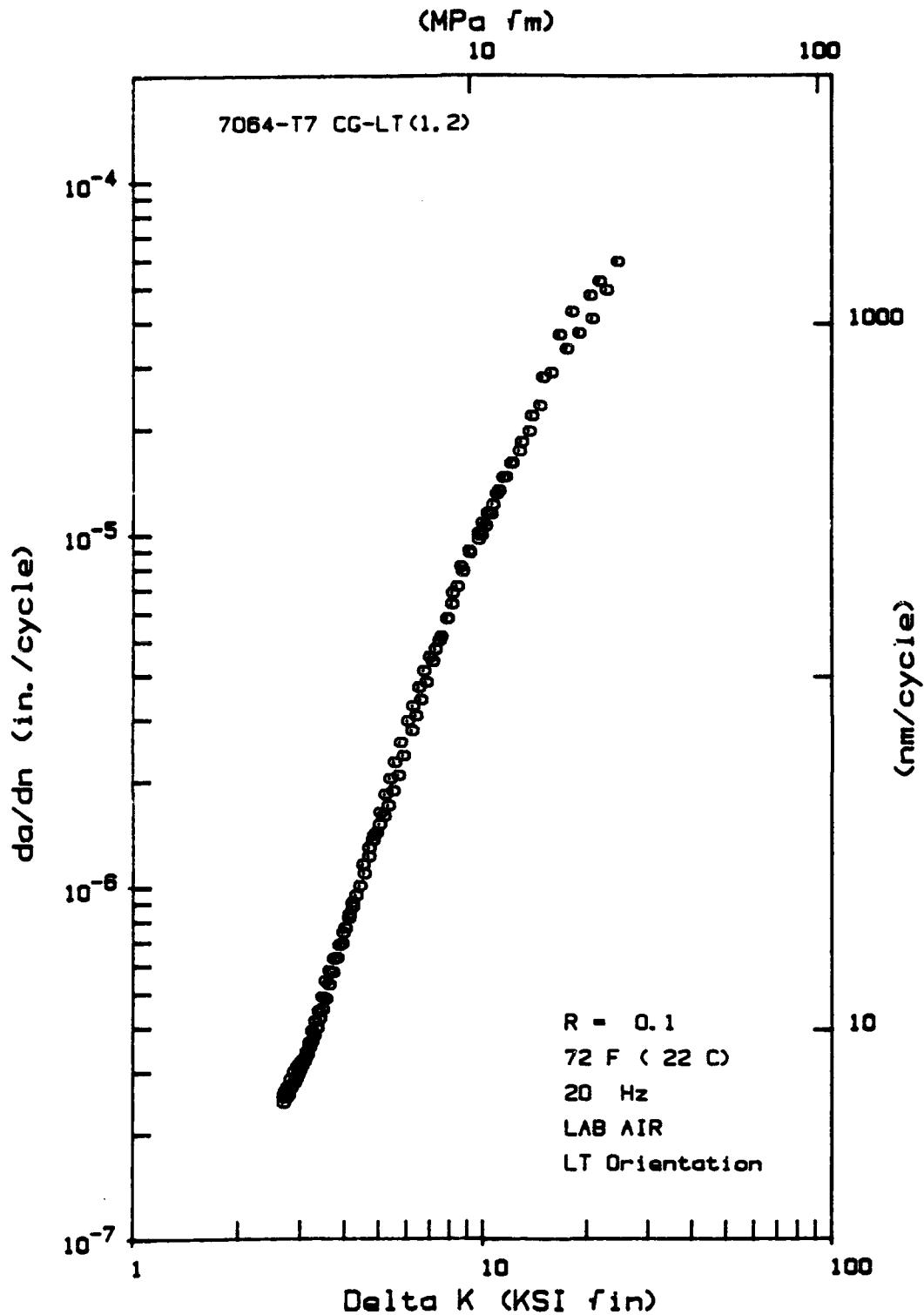


FIGURE N2. FATIGUE CRACK GROWTH RATE DATA for Two 7064-T74511 Extrusion Specimens. (L-T ORIENTATION). AIR FORCE. 437

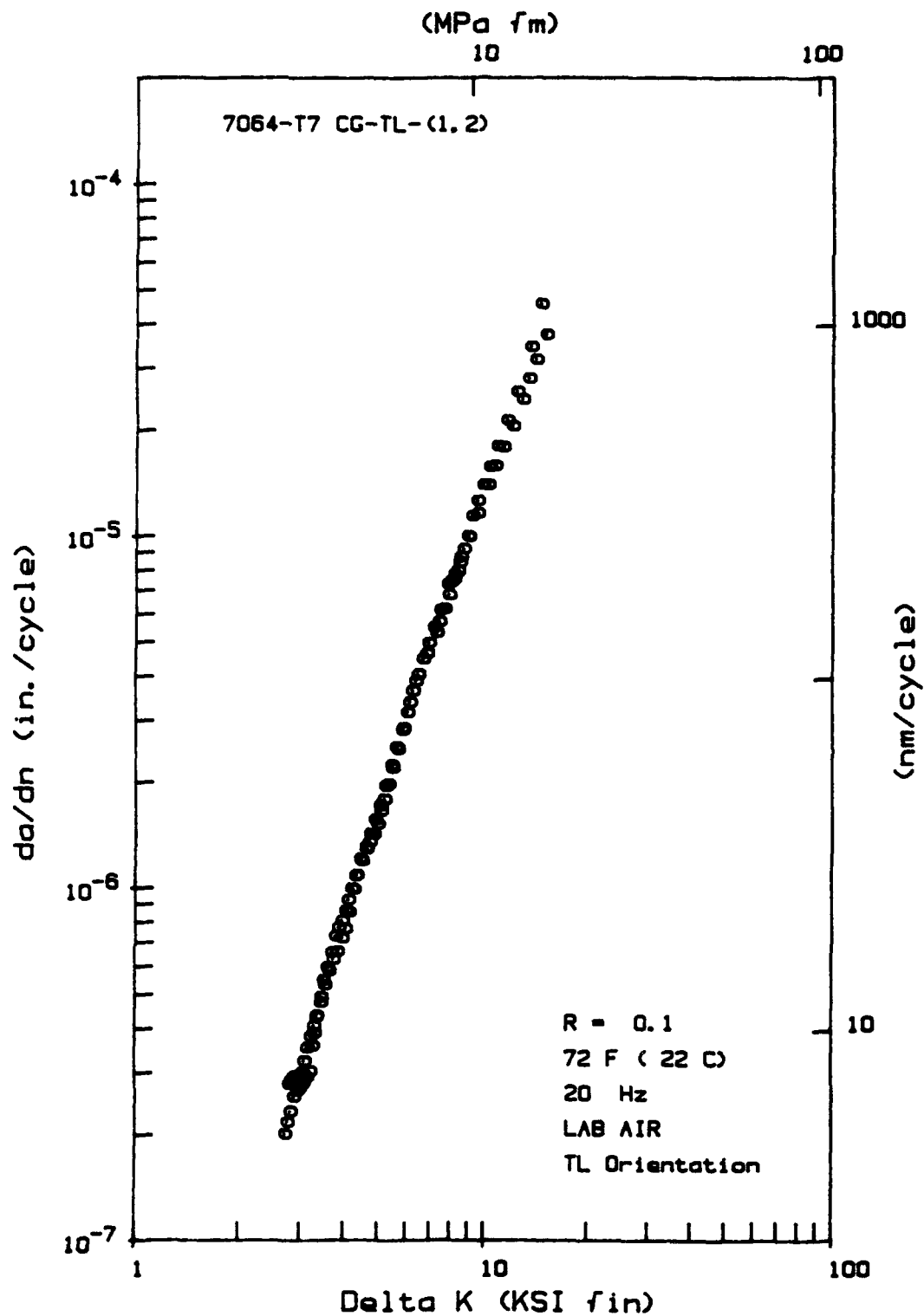


FIGURE N3. FATIGUE CRACK GROWTH RATE DATA for Two 7064-T74511 Extrusion Specimens. (T-L ORIENTATION). AIR FORCE. 438

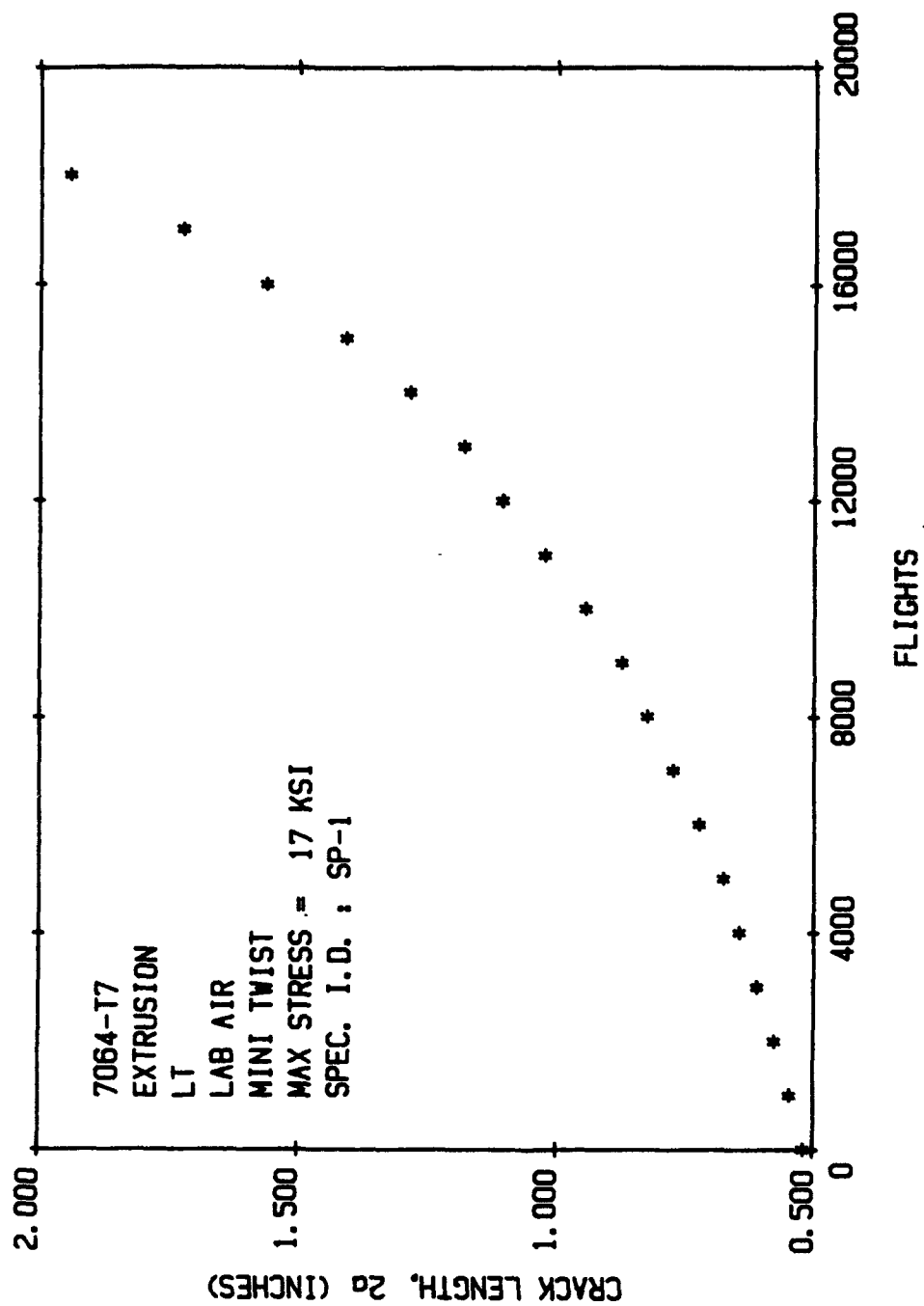


FIGURE N4. Mini-TWIST Spectrum Fatigue Crack Length vs Flights Data for 7064-T74511 Extrusion.  
Air Force.

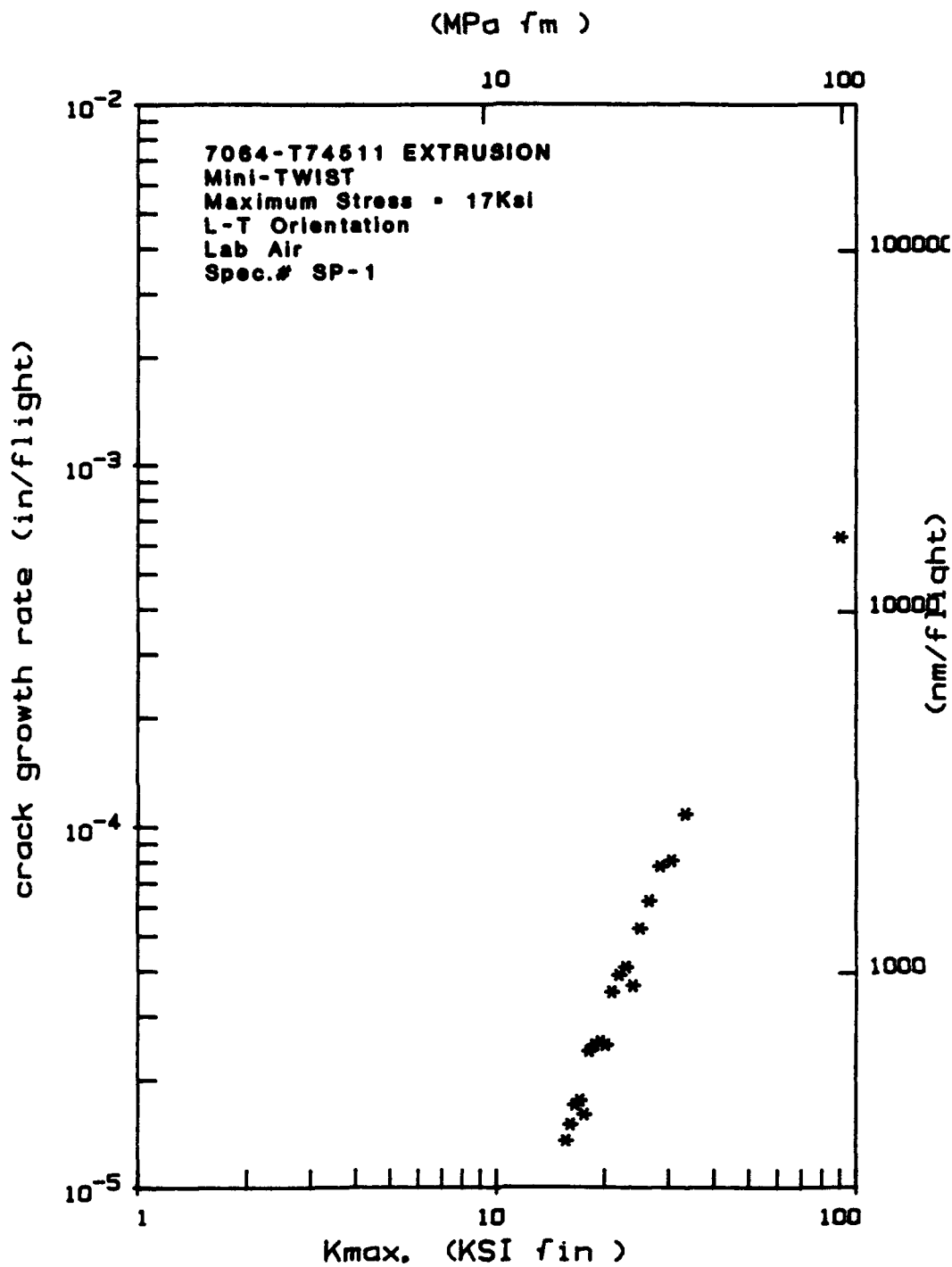


FIGURE N5. Mini-TWIST Spectrum Fatigue Crack Growth Rate Data for 7064-T74511 Extrusion. Air Force.

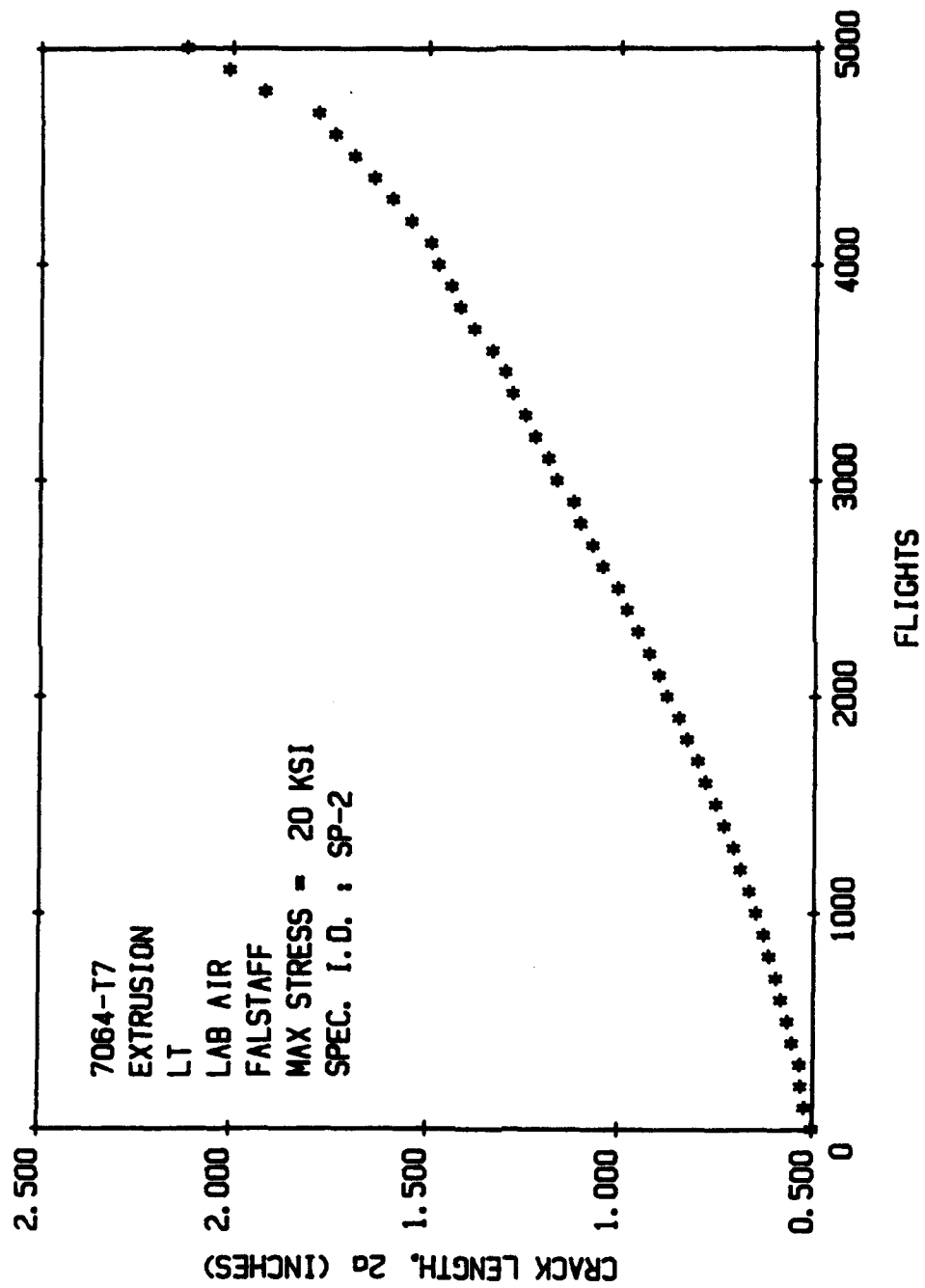


FIGURE N6. FALSTAFF Spectrum Fatigue Crack Length vs Flights Data for 7064-T74511 Extrusion. Air Force.

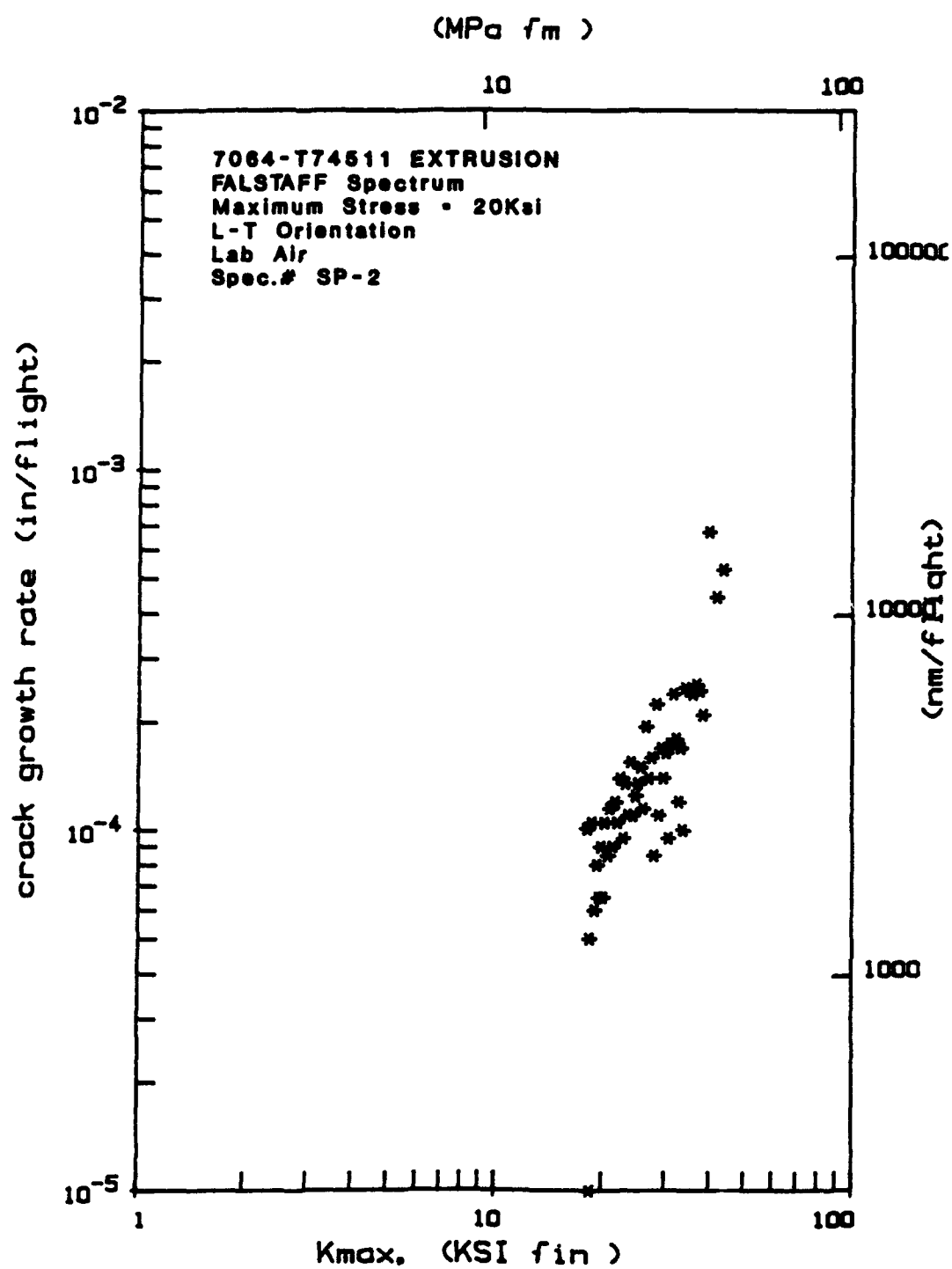


FIGURE N7. FALSTAFF Spectrum Fatigue Crack Growth Rate Data for 7064-T74511 Extrusion. Air Force.

## **APPENDIX O**

### **7064-T74 HAND FORGING 1.6"x4"x18"**

#### **INTRODUCTION**

The Kaiser P/M aluminum alloy 7064-T74 1.6"x4"x18" forgings were received in December 1986. Forged 7064 was tested by Lockheed, LTV, Martin Marietta, McDonnell Aircraft Company, and the Air Force.

#### **TESTING**

Mechanical properties (tension, compression, shear, bearing and fracture toughness), fatigue, and constant amplitude fatigue crack growth tests were generated according to ASTM standards, unless otherwise specified.

Spectrum fatigue crack growth rate tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

TABLE 01  
TENSILE RESULTS AT t/2 LOCATION FOR  
KAISER 7064-T74 HAND FORGINGS

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)
MCAIR, ST. LOUIS	RT	LONG	80.0	74.0	13.0		
			80.0	73.0	14.0		
			81.5	75.0	11.0		
			80.5	74.0	13.0		
LOCKHEED, GEORGIA	RT	LONG	77.2	69.7			9.9
			81.9	75.0			11.2
			81.0	75.2			10.5
			84.9	79.0			10.6
			81.5	74.7			10.2
			81.1	74.1			10.1
			80.0	74.0			10.1
			84.1	78.4			9.9
			80.6	73.6			10.3
80.5	74.3			10.1			
MARTIN MARIETTA, LOUISIANA	RT	LONG	79.5	71.4	5.0	41.6	10.1
			79.4	70.9	12.0	44.0	10.2
			78.6	70.6	14.0	37.9	10.1
LTV	RT	LONG	80.6	74.3	13.3	32.4	9.4
			79.1	72.6	13.7	29.8	9.5
			78.7	71.7	15.4	38.9	9.5
			82.0	75.9	10.6	31.0	9.7
AVERAGE			80.6	73.9	12.3	36.5	10.1
STANDARD DEVIATION			1.8	2.3	2.8	5.5	0.4

**TABLE 02**  
**TENSILE RESULTS AT t/2 LOCATION FOR**  
**KAISER 7064-T74 HAND FORGINGS**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)
MCAIR, ST. LOUIS	RT	L TRANS	80.0	72.0	8.0		
			80.0	72.5	9.0		
			80.5	73.0	8.0		
			80.0	72.5	8.0		
LOCKHEED, GEORGIA	RT	L TRANS	83.0	77.1			10.8
			80.2	73.3			9.6
			80.5	73.7			9.9
			78.9	72.9			10.0
			79.9	73.0			10.7
			79.9	72.5			9.7
			78.6	71.8			10.6
			79.8	71.3			10.6
			78.0	71.4			10.2
78.9	70.6			10.4			
MARTIN MARIETTA, LOUISIANA	RT	L TRANS	78.5	70.0	6.0	6.1	10.0
			79.2	71.3	8.0	10.2	10.0
			77.5	69.1	13.0	32.7	10.0
LTV	RT	L TRANS	77.8	70.9	8.0	15.3	9.5
			78.1	70.6	10.0	19.3	9.7
			77.8	68.8	8.0	11.7	10.0
			77.2	68.7	7.0	9.7	10.3
AVERAGE			79.3	71.8	8.5	15.0	10.1
STANDARD DEVIATION			1.3	1.9	1.8	8.9	0.4

**TABLE 03**  
**TENSILE RESULTS AT t/2 LOCATION FOR**  
**KAISER 7064-T74 HAND FORGINGS**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)
<hr/>							
MCAIR, ST. LOUIS	RT	S TRANS	82.5	77.0	10.0		
			83.0	76.5	6.0		
			81.5	75.0	6.0		
			82.0	76.0	7.0		
		AVERAGE	82.3	76.1	7.3		
		STANDARD DEVIATION	0.6	0.9	1.9		

TABLE 04  
COMPRESSION RESULTS AT t/2 LOCATION FOR  
KAISER 7064-T74 HAND FORGINGS

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCAIR, ST. LOUIS	RT	LONG	75.5	11.2
			77.5	11.5
			75.0	10.8
LOCKHEED, GEORGIA	RT	LONG	76.6	10.6
			78.0	
			83.4	10.4
			79.9	10.6
			83.5	
			78.5	
			78.1	10.5
MARTIN MARIETTA, LOUISIANA	RT	LONG	76.4	11.0
			77.2	11.0
			75.3	10.9
LTV	RT	LONG	80.4	11.5
			77.7	11.4
			76.4	12.5
			79.6	11.8
AVERAGE			78.2	11.1
STANDARD DEVIATION			2.5	0.6

**TABLE 05**  
**COMPRESSION RESULTS AT t/2 LOCATION FOR**  
**KAISER 7064-T74 HAND FORGINGS**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCAIR, ST. LOUIS	RT	L TRANS	75.0	11.2
			76.5	11.8
			76.0	11.9
LOCKHEED, GEORGIA	RT	L TRANS	72.9	
			80.5	
			75.3	11.2
			78.3	11.3
			77.7	11.1
			73.8	9.8
MARTIN MARIETTA, LOUISIANA	RT	L TRANS	72.0	9.7
			76.4	11.2
			76.1	11.1
LTV	RT	L TRANS	76.1	11.1
			77.9	11.1
			76.8	12.0
			78.7	11.8
			74.9	11.7
AVERAGE			76.2	11.2
STANDARD DEVIATION			2.1	0.7

**TABLE 06**  
**SLOTTED SHEAR RESULTS FOR**  
**KAISER 7064-T74 HAND FORGINGS**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>ULTIMATE STRENGTH (KSI)</b>
<hr/>		
<b>MCAIR, ST. LOUIS</b>	<b>LONG</b>	<b>53.5</b>
		<b>47.5</b>
		<b>46.5</b>
	<b>AVERAGE</b>	<b>49.2</b>
	<b>STANDARD DEVIATION</b>	<b>3.8</b>

**TABLE 07**  
**AMSLER DOUBLE SHEAR RESULTS FOR**  
**KAISER 7064-T74 HAND FORGINGS**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>ULTIMATE STRENGTH (KSI)</b>
<hr/>		
<b>LOCKHEED, GEORGIA</b>	<b>L-T</b>	<b>50.0</b>
		<b>51.8</b>
		<b>50.4</b>
	<b>AVERAGE</b>	<b>50.7</b>
	<b>STANDARD DEVIATION</b>	<b>0.9</b>

**TABLE 08**  
**IOSIPESCU SHEAR RESULTS FOR**  
**KAISER 7064-T74 HAND FORGINGS**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>ULTIMATE STRENGTH (KSI)</b>
<b>LTV</b>	<b>LONG</b>	50.5
		52.5
		48.0
		48.9
		51.5
		51.3
		51.7
	<b>AVERAGE</b>	50.6
	<b>STANDARD DEVIATION</b>	1.5

**TABLE 09**  
**IOSIPESCU SHEAR RESULTS FOR**  
**KAISER 7064-T74 HAND FORGINGS**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>ULTIMATE STRENGTH (KSI)</b>
<b>LTV</b>	<b>L TRANS</b>	50.2
		51.3
		51.2
		52.7
		49.5
		53.7
		51.8
	<b>AVERAGE</b>	51.5
	<b>STANDARD DEVIATION</b>	1.4

TABLE 010  
BEARING RESULTS FOR KAISER  
7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
-----				
LOCKHEED, GEORGIA	LONG	1.5	137.0	116.0
			115.0	105.0
			139.0	114.0
LTV	LONG	1.5	132.8	112.4
			132.4	112.1
			137.7	115.9
AVERAGE			132.3	112.6
STANDARD DEVIATION			8.9	4.1

TABLE 011  
BEARING RESULTS FOR KAISER  
7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)		
LTV	L TRANS	1.5	134.3	116.6		
			135.2	114.7		
			139.1	116.5		
			138.5	117.1		
			AVERAGE		136.8	116.2
			STANDARD DEVIATION		2.4	1.1

TABLE 012  
BEARING RESULTS FOR KAISER  
7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCAIR, ST. LOUIS	LONG	2.0	148.0 149.0 143.0	117.0 112.0
LOCKHEED, GEORGIA	LONG	2.0	168.0 169.0 170.0	135.0 123.0 126.0
LTV	LONG	2.0	165.1 170.6 176.1	131.9 143.1 137.5
AVERAGE			162.1	128.2
STANDARD DEVIATION			12.0	10.6

TABLE 013  
BEARING RESULTS FOR KAISER  
7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCAIR, ST. LOUIS	L TRANS	2.0	149.0 149.0 151.0	119.0 116.0 119.0
LTV	L TRANS	2.0	173.0 172.1 171.8 168.1	135.9 134.6 135.0 142.8
AVERAGE			162.0	128.9
STANDARD DEVIATION			11.7	10.6

**TABLE 014**  
**FRACTURE TOUGHNESS RESULTS FOR**  
**KAISER 7064-T74 HAND FORGINGS**

COMPANY	ORIENTATION	KIC (KSI IN <sup>0.5</sup> )	Kq (KSI IN <sup>0.5</sup> )	COMMENT
MCAIR, ST. LOUIS	L-T	24.1 27.5		VALID VALID
LOCKHEED, GEORGIA	L-T	26.0 29.0		VALID VALID
MARTIN MARIETTA, LOUISIANA	L-T		27.2 23.6	(1) (1)
LTV	L-T		24.1 26.4 29.4	(2) (3) (2) (3) (2)
AVERAGE		26.7	26.1	
STANDARD DEVIATION		2.1		

- (1): INVALID DUE TO  $a/W=0.552 > 0.55$   
(2): INVALID DUE TO TEST SPECIMEN FRACTURE SURFACE  
VIOLATED KIC REQUIREMENTS  
(3): INVALID DUE TO  $K_{max}$  PRECRACK  $> 0.6 K_q$

**TABLE 015**  
**FRACTURE TOUGHNESS RESULTS FOR**  
**KAISER 7064-T74 HAND FORGINGS**

COMPANY	ORIENTATION	KIC	K <sub>q</sub>	COMMENT
		(KSI IN <sup>-0.5</sup> )	(KSI IN <sup>-0.5</sup> )	
MCAIR, ST. LOUIS	T-L	17.8		VALID
		17.0		VALID
MARTIN MARIETTA, LOUISIANA	T-L		18.7	(1)
LTV	T-L		30.2	
			21.1	(2),
		27.9		VALID
	AVERAGE	20.9	23.3	
	STANDARD DEVIATION	6.1	6.1	

- (1): INVALID DUE TO  $a/W=0.552 > 0.55$   
(2): INVALID DUE TO TEST SPECIMEN FRACTURE SURFACE  
VIOLATED KIC REQUIREMENTS  
(3): INVALID DUE TO  $K_{max} \text{ PRECRACK} > 0.6 K_q$

**TABLE 016**  
**FRACTURE TOUGHNESS RESULTS FOR**  
**KAISER 7064-T74 HAND FORGINGS**

COMPANY	ORIENTATION	K <sub>IC</sub> (KSI IN <sup>0.5</sup> )	K <sub>q</sub> (KSI IN <sup>0.5</sup> )	COMMENT
MCAIR, ST. LOUIS	S-T	19.9	20.3	(1), (2) VALID
MARTIN MARIETTA, LOUISIANA	S-T		15.8 14.3	(1) (1)
	AVERAGE	19.9	16.8	
	STANDARD DEVIATION	0.0	3.1	

- (1): INVALID DUE TO SURFACE TRACE/AVERAGE CRACK ERROR VALUE > VALID REQ  
(2): AVERAGE CRACK/W VALUE LESS THAN VALID REQUIREMENT

TABLE 017  
FRACTURE TOUGHNESS RESULTS FOR  
KAISER 7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	K <sub>IC</sub> (KSI IN <sup>-0.5</sup> )	K <sub>Q</sub> (KSI IN <sup>-0.5</sup> )	COMMENT
MARTIN MARIETTA, LOUISIANA	S-L	16.7 15.0	19.3	(1)
	AVERAGE	15.9	19.3	
	STANDARD DEVIATION	1.2	0.0	

(1): INVALID DUE TO  $a/W=0.552 > 0.55$

**TABLE 018**  
**FATIGUE RESULTS WITH  $K_t=1.0$  AND  $R=-1.0$  FOR**  
**KAISER 7064-T74 HAND FORGINGS**

COMPANY	ORIENTATION	LIMIT STRESS (KSI)	CYCLES TO FAILURE
MCAIR, ST. LOUIS	LONG	60.0	2,270
		55.0	5,140
		50.0	10,750
		45.0	18,150
		40.0	86,100
		35.0	206,670
		30.0	2,560,000 *
		25.0	1,000,000 *

(\*): INDICATES A RUN OUT TEST

**TABLE 019**  
**FATIGUE RESULTS WITH  $K_t=1.0$  AND  $R=0.1$  FOR**  
**KAISER 7064-T74 HAND FORGINGS**

COMPANY	ORIENTATION	LIMIT STRESS (KSI)	CYCLES TO FAILURE
LTV	LONG	50.0	11,600
		46.1	15,100
		44.9	17,400
		44.0	12,100
		43.0	28,200
		42.9	18,800
		41.7	28,000
		40.9	28,300
		40.1	10,700
		39.7	7,400
		36.9	24,700
		36.0	285,600
		35.2	18,000
		34.4	318,700
		33.2	3,000,000 *

(\*): INDICATES A RUN-OUT TEST

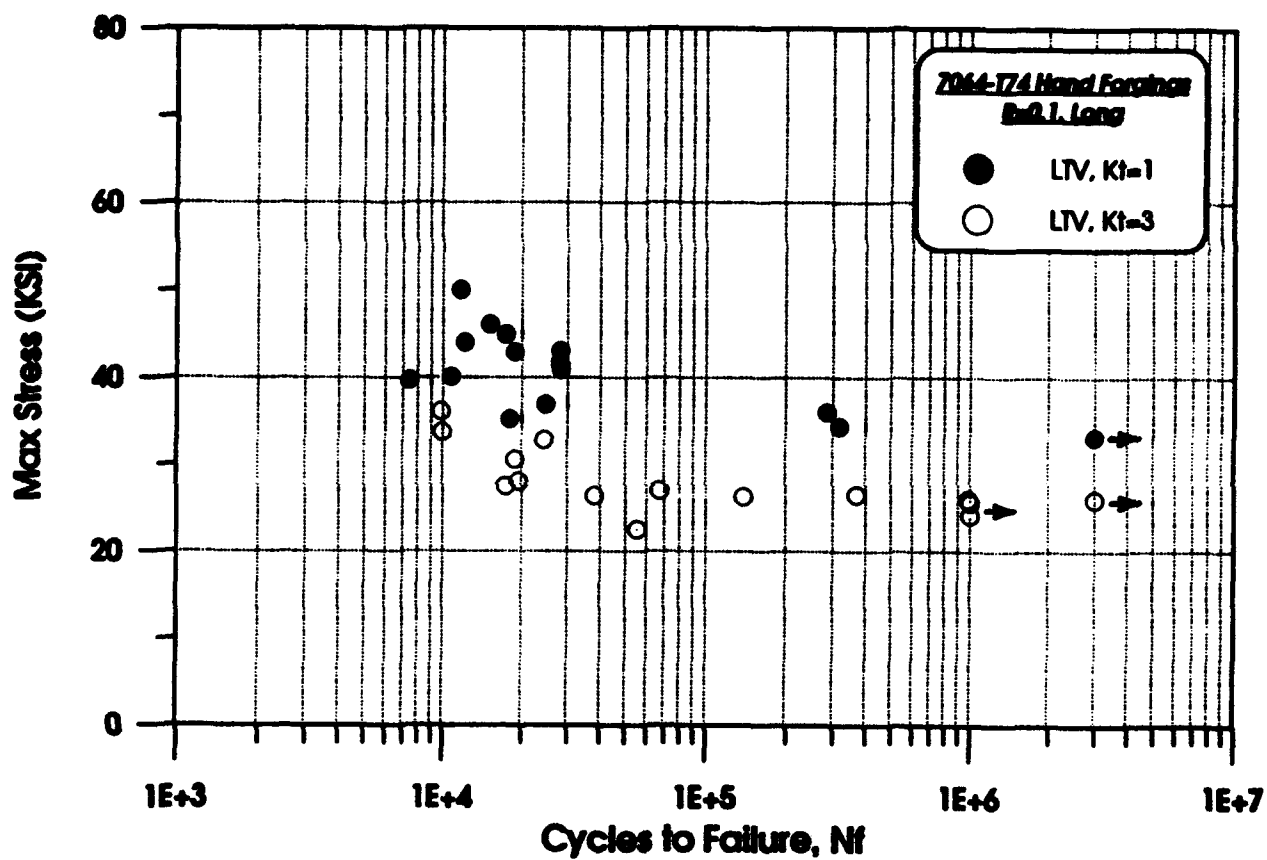


FIGURE O1. FATIGUE DATA for 7064-T74 Hand Forgings (Longitudinal Orientation  $R=0.1$ ,  $K_t=1$  and  $K_t=3$ ). LTV.

**TABLE O20**  
**FATIGUE RESULTS WITH Kt=3.0 AND R=0.1 FOR**  
**KAISER 7064-T74 HAND FORGINGS**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>LIMIT STRESS (KSI)</b>	<b>CYCLES TO FAILURE</b>
<hr/>			
<b>LTV</b>	<b>LONG</b>	<b>36.1</b>	<b>9,800</b>
		<b>33.7</b>	<b>9,900</b>
		<b>32.8</b>	<b>24,500</b>
		<b>30.5</b>	<b>18,900</b>
		<b>28.0</b>	<b>19,600</b>
		<b>27.5</b>	<b>17,400</b>
		<b>27.0</b>	<b>67,100</b>
		<b>26.5</b>	<b>368,300</b>
		<b>26.4</b>	<b>38,100</b>
		<b>26.3</b>	<b>138,700</b>
		<b>26.0</b>	<b>983,800</b>
		<b>26.0</b>	<b>3,000,000 *</b>
		<b>25.6</b>	<b>1,000,000 *</b>
		<b>24.1</b>	<b>1,000,000 *</b>
		<b>22.5</b>	<b>55,500</b>

**(\*): INDICATES A RUN-OUT TEST**

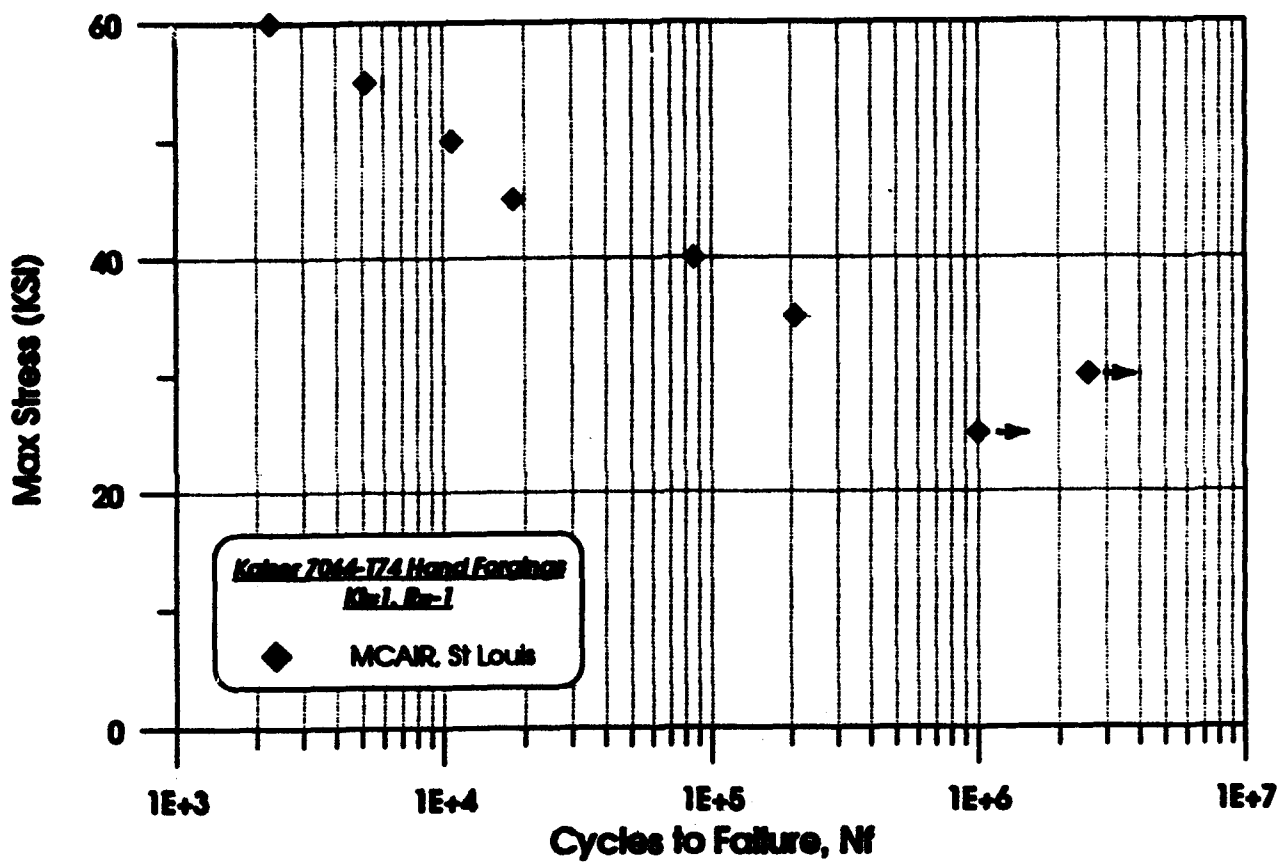
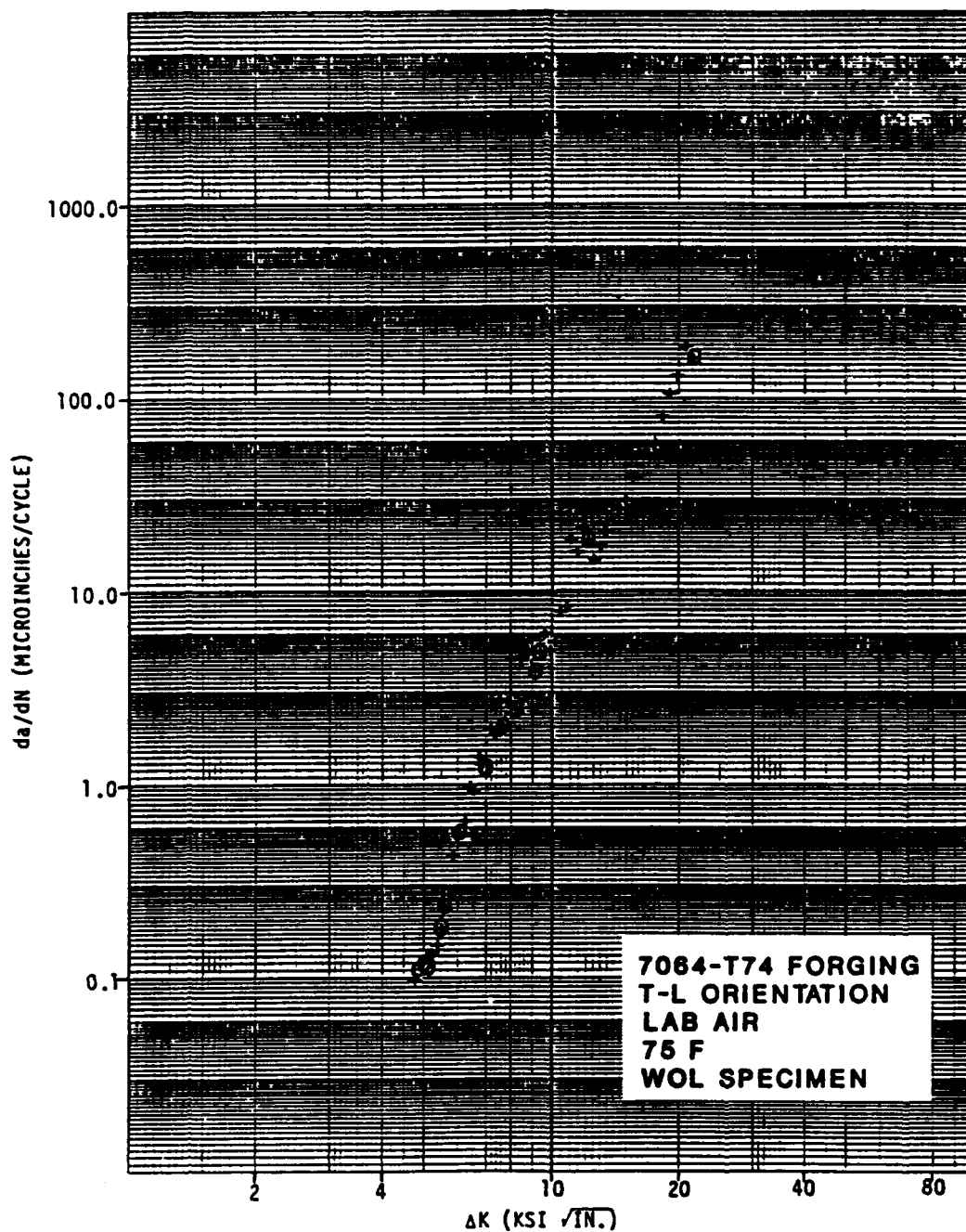


FIGURE O2. FATIGUE DATA FOR 7064-T74 HAND FORGINGS (Longitudinal Orientation,  $R=-1.0$ , and  $K_t=1$ ). McDonnell Aircraft Company.



● DENOTES THAT DATA POINT IS INVALID PER ASTM E647-83, PARAGRAPH 8.6.4.

FIGURE O3. FATIGUE CRACK GROWTH RATE DATA for 7064-T74 Forging (T-L Orientation, WOL Type Specimen). McDonnell Aircraft Company.

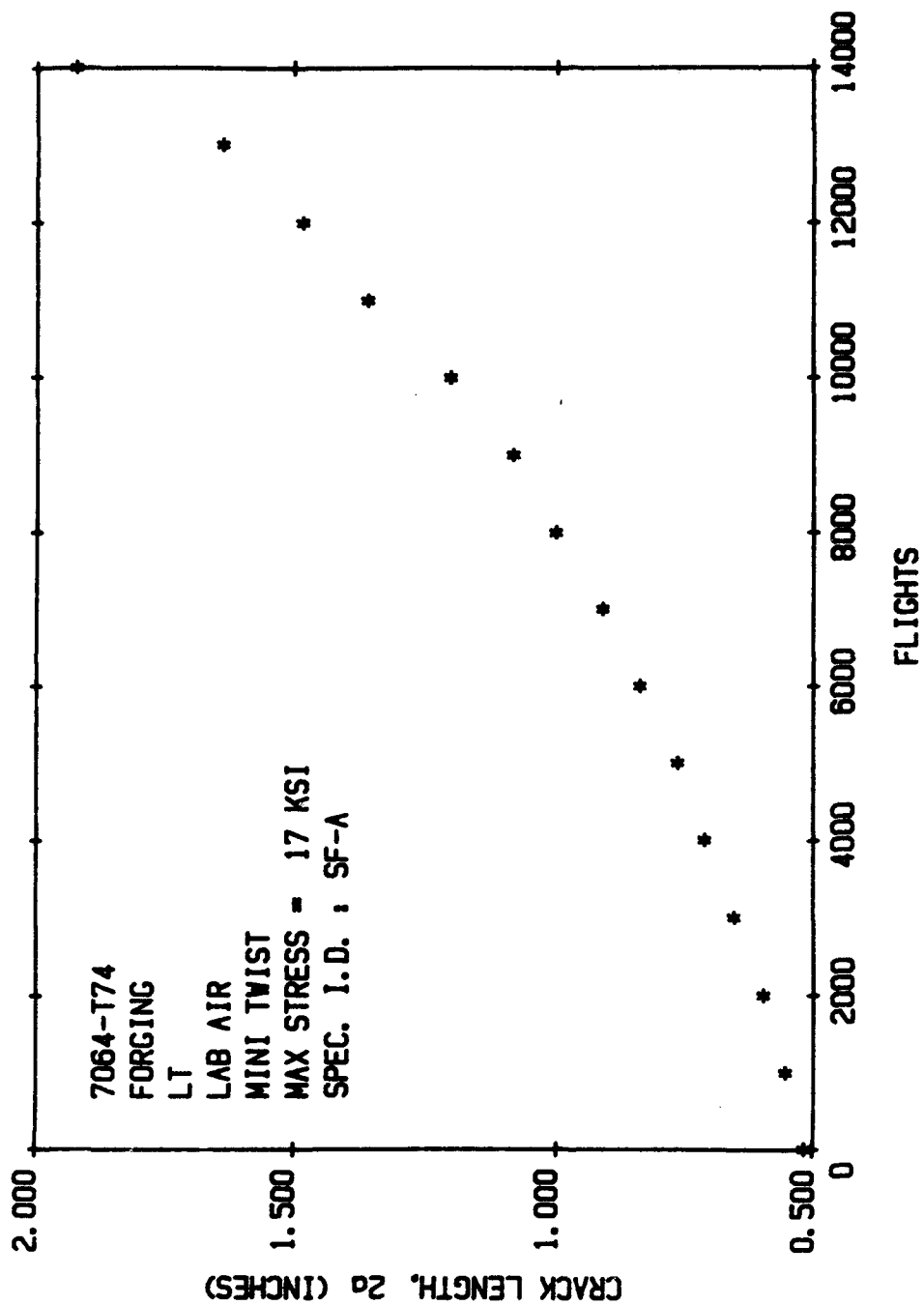


FIGURE O4. Mini-TWIST Spectrum Fatigue Crack Length vs Flights Data for 7064-T74 Forging.  
Air Force.

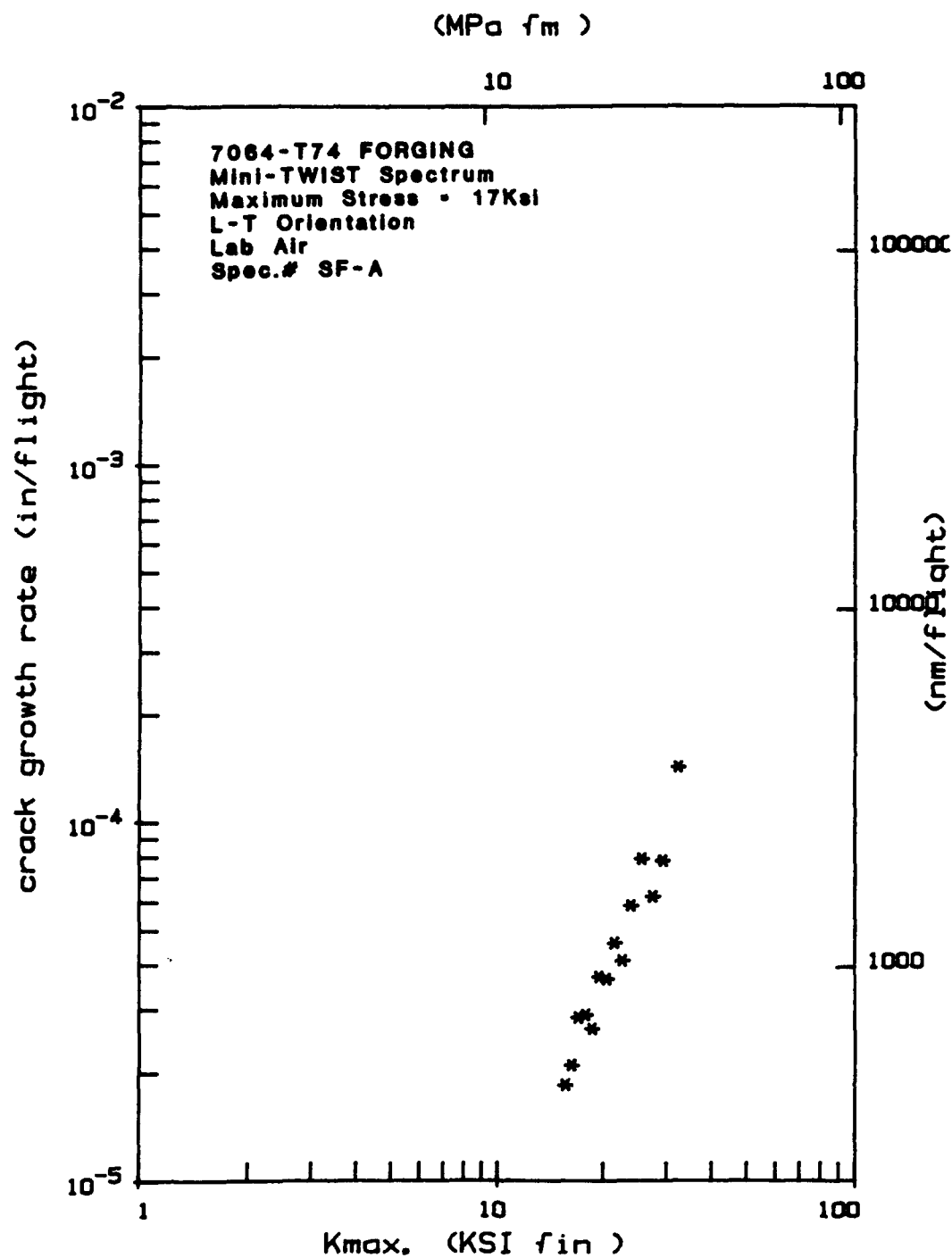


FIGURE O5. Mini-TWIST Spectrum Fatigue Crack Growth Rate Data for 7064-T74 Forging. Air Force.

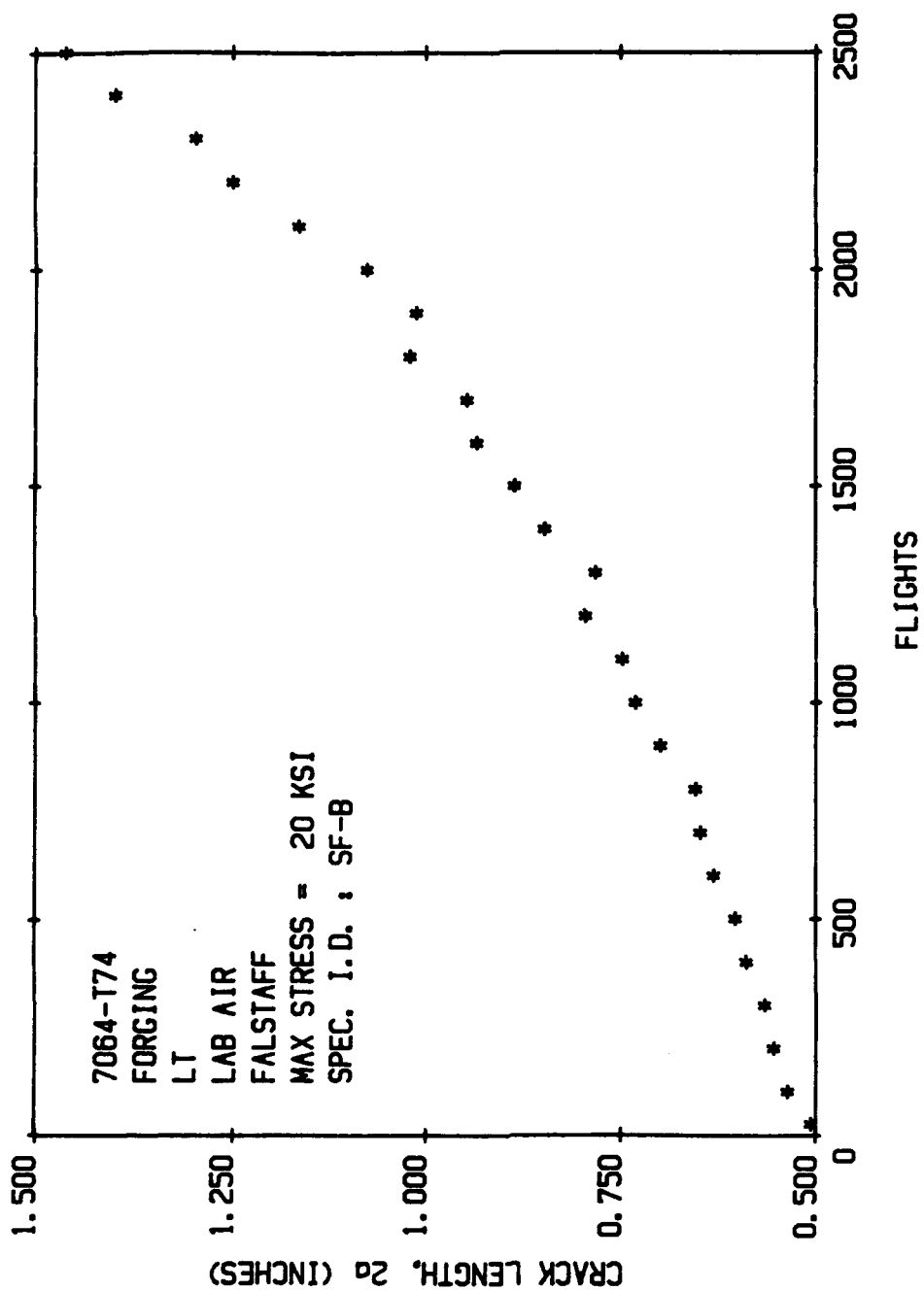


FIGURE O6. FALSTAFF Spectrum Fatigue Crack Length vs Flights Data for 7064-T74 Forging.  
Air Force.

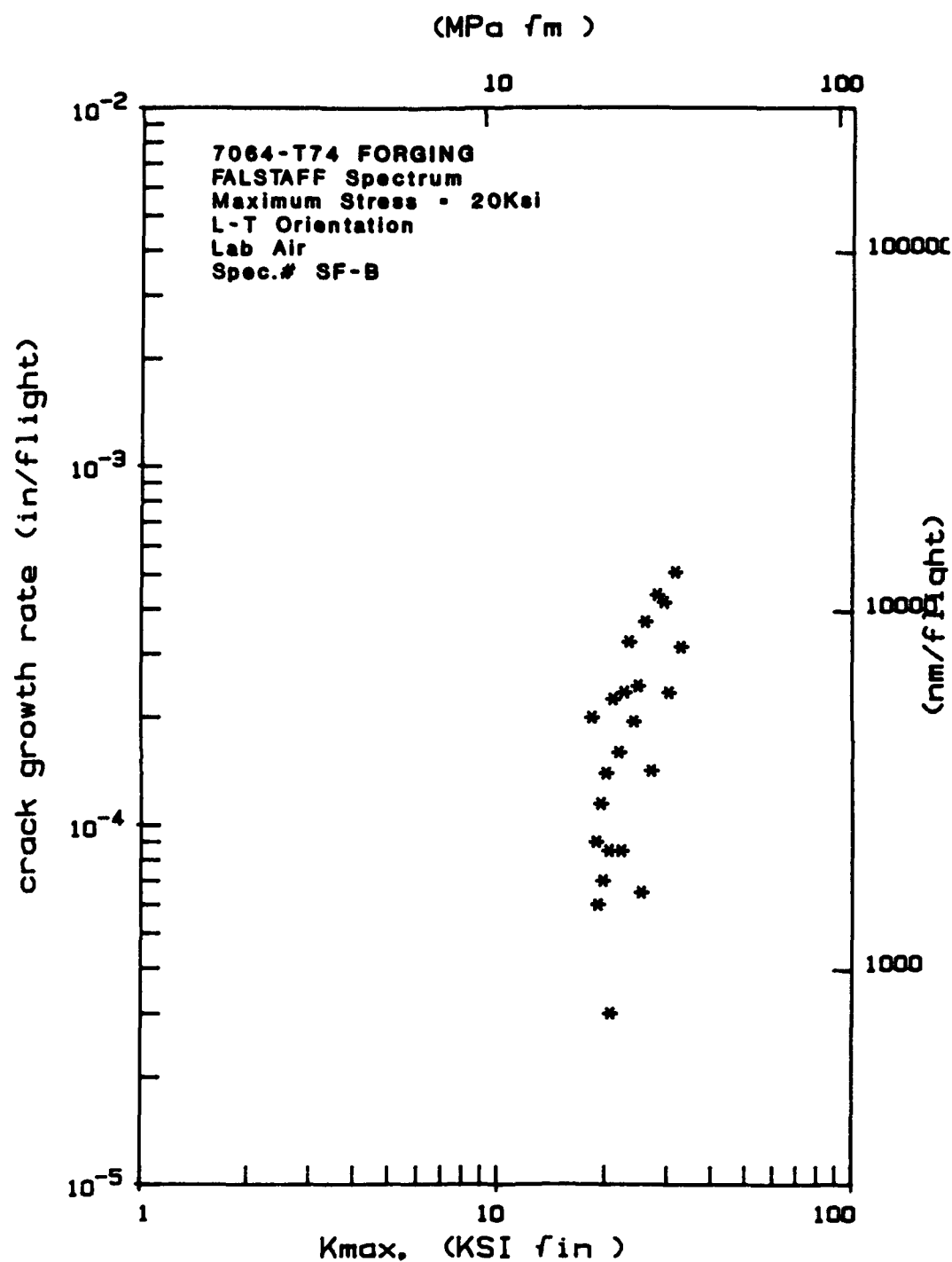


FIGURE 07. FALSTAFF Spectrum Fatigue Crack Growth Rate Data for 7064-T74 Forging. Air Force.

## **APPENDIX P**

### **CW67 SHEET 0.063"X16"X48"**

#### **INTRODUCTION**

The Alcoa P/M aluminum alloy CW67 0.063 inch sheets were received April 1989. CW67 sheets were tested by Martin Marietta and McDonnell Aircraft Company.

#### **TESTING**

Mechanical properties (tension, compression, shear, bearing and fracture toughness), and constant amplitude fatigue crack growth tests were generated according to ASTM standards, unless otherwise specified.

**TABLE P1**  
**TENSILE RESULTS FOR ALCOA**  
**CW67 SHEET (0.063" X 16" X 48")**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	RT	LONG	81.5	77.5	8.0	10.0	9.8
MARIETTA, LOUISIANA			81.9	78.7	7.0	10.0	9.7
			82.9	79.5		6.7	9.8
MCDONNELL	RT	LONG	80.0	77.0	6.0		10.0
DOUGLAS			80.0	77.5	8.0		10.4
			81.0	78.5	6.0		10.0
AVERAGE			81.2	78.1	7.0	8.9	10.0
STANDARD DEVIATION			1.1	0.9	1.0	1.9	0.3

**TABLE P2**  
**TENSILE RESULTS FOR ALCOA**  
**CW67 SHEET (0.063" X 16" X 48")**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	RT	L TRANS	83.5	80.8		6.7	9.9
MARIETTA, LOUISIANA			83.9	82.0	3.0	3.3	10.0
			83.7	80.5	2.0	6.7	10.1
MCDONNELL	RT	L TRANS	87.5	83.0	4.0		10.3
DOUGLAS			86.5	82.0	5.0		10.3
			86.5	82.0	5.0		10.4
AVERAGE			85.3	81.7	3.8	5.6	10.2
STANDARD DEVIATION			1.8	0.9	1.3	2.0	0.2

**TABLE P3**  
**COMPRESSION RESULTS FOR ALCOA**  
**CW67 SHEET (0.063" X 16" X 48")**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCDONNELL	RT	LONG		11.2
DOUGLAS				11.5
			72.0	10.3
		AVERAGE	72.0	11.0
		STANDARD DEVIATION	0.0	0.6

**TABLE P4**  
**COMPRESSION RESULTS FOR ALCOA**  
**CW67 SHEET (0.063" X 16" X 48")**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCDONNELL	RT	L TRANS		10.3
DOUGLAS				10.8
				11.2
		AVERAGE		10.8
		STANDARD DEVIATION		0.5

**TABLE P5**  
**SLOTTED SHEAR RESULTS FOR ALCOA**  
**CW67 SHEET (0.063" X 16" X 48")**

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
<hr/>		
MCDONNELL DOUGLAS	LONG	31.0
		30.0
		29.3
	AVERAGE	30.1
	STANDARD DEVIATION	0.9

**TABLE P6**  
**BEARING RESULTS FOR ALCOA**  
**CW67 SHEET (0.063" X 16" X 48")**

COMPANY	ORIENTATION	e/D	BEARING		BEARING
			ULT.	STR.	YIELD STR.
			(KSI)		(KSI)
MCDONNELL	LONG	1.5	117.1		101.3
DOUGLAS			124.3		107.7
			125.5		111.1
AVERAGE			122.3		106.7
STANDARD DEVIATION			4.5		5.0

**TABLE P7**  
**BEARING RESULTS FOR ALCOA**  
**CW67 SHEET (0.063" X 16" X 48")**

COMPANY	ORIENTATION	e/D	BEARING		BEARING
			ULT.	STR.	YIELD STR.
			(KSI)		(KSI)
MCDONNELL	L TRANS	1.5	127.1		112.0
DOUGLAS			126.1		108.9
			126.6		112.9
AVERAGE			126.6		111.3
STANDARD DEVIATION			0.5		2.1

**TABLE P8**  
**BEARING RESULTS FOR ALCOA**  
**CW67 SHEET (0.063" X 16" X 48")**

COMPANY	ORIENTATION	e/D	BEARING		BEARING
			ULT.	STR.	YIELD STR.
			(KSI)		(KSI)
MCDONNELL	LONG	2.0	169.4		148.8
DOUGLAS			162.0		116.3
			163.5		139.5
AVERAGE			165.0		134.9
STANDARD DEVIATION			3.9		16.7

**TABLE P9**  
**BEARING RESULTS FOR ALCOA**  
**CW67 SHEET (0.063" X 16" X 48")**

COMPANY	ORIENTATION	e/D	BEARING		BEARING
			ULT.	STR.	YIELD STR.
			(KSI)		(KSI)
MCDONNELL	L TRANS	2.0	166.1		146.4
DOUGLAS			168.5		146.6
			166.2		146.4
AVERAGE			166.9		146.5
STANDARD DEVIATION			1.4		0.1

TABLE P10

R-CURVE DATA FOR CW67 0.063 SHEET  
(SPECIMEN 32)  
McDonnell Aircraft Company

SPECIMEN IDENTIFICATION: 32  
MATERIAL DESCRIPTION: CW67 HIGH STRENGTH ALUMINUM SHEET  
SPECIMEN TYPE: C(T) (COMPACT SPECIMEN)  
SPECIMEN ORIENTATION: L-T  
YIELD STRENGTH: 77.7 KSI  
SPECIMEN THICKNESS: 0.071 IN  
SPECIMEN WIDTH: 3.999 IN

SPECIMEN IS INVALID PER ASTM E561-86, PARA. 7.5

APPLIED LOAD (lbs)	PHYSICAL CRACK LENGTH (in)	Kr (UNCORRECTED) (psi /in)	EFFECTIVE CRACK LENGTH (in)	Kr (CORRECTED) (psi /in)
1,025	1.519	49,842	1.591	52,248
1,050	1.523	51,181	1.599	53,808
1,250	1.533	61,348	1.649	66,212
1,325	1.592	67,582	1.739	74,594
1,375	1.610	70,986	1.777	79,483
1,400	1.613	72,406	1.788	81,590
1,425	1.638	74,930	1.831	85,575
1,450	1.638	76,245	1.840	87,675
1,475	1.642	77,762	1.856	90,199
1,500	1.660	80,039	1.894	94,283
1,525	1.662	81,493	1.910	96,969
1,550	1.663	82,874	1.924	99,627
1,600	1.667	85,818	1.963	105,834
1,650	1.678	89,128	2.022	114,190
1,700	1.684	92,202	2.092	124,368
1,725	1.706	94,972	***	***
1,750	FAILURE	---	---	---

\*\*\* Indicates that the equation for Kr (Corrected) did not converge to a solution.

**TABLE P11**

**R-CURVE DATA FOR CW67 0.063 SHEET  
(SPECIMEN 33)  
McDonnell Aircraft Company**

**SPECIMEN IDENTIFICATION: 33**  
**MATERIAL DESCRIPTION: CW67 HIGH STRENGTH ALUMINUM SHEET**  
**SPECIMEN TYPE: C(T) (COMPACT SPECIMEN)**  
**SPECIMEN ORIENTATION: L-T**  
**YIELD STRENGTH: 77.7 KSI**  
**SPECIMEN THICKNESS: 0.071 IN**  
**SPECIMEN WIDTH: 4.002 IN**

<b>APPLIED LOAD (lbs)</b>	<b>PHYSICAL CRACK LENGTH (in)</b>	<b>Kr (UNCORRECTED) (psi /in)</b>	<b>EFFECTIVE CRACK LENGTH (in)</b>	<b>Kr (CORRECTED) (psi /in)</b>
920	1.509	44,397	1.565	46,045
940	1.533	46,088	1.594	47,956
1,000	1.545	49,395	1.615	51,743
1,020	1.548	50,476	1.622	52,997
1,060	1.565	53,059	1.648	56,048
1,100	1.569	55,188	1.659	58,602
1,140	1.573	57,349	1.672	61,243
1,180	FAILURE	---	---	---

TABLE P12

R-CURVE DATA FOR CW67 0.063 SHEET  
(SPECIMEN 34)  
McDonnell Aircraft Company

SPECIMEN IDENTIFICATION: 34  
 MATERIAL DESCRIPTION: CW67 HIGH STRENGTH ALUMINUM SHEET  
 SPECIMEN TYPE: C(T) (COMPACT SPECIMEN)  
 SPECIMEN ORIENTATION: T-L  
 YIELD STRENGTH: 82.3 KSI  
 SPECIMEN THICKNESS: 0.071 IN  
 SPECIMEN WIDTH: 4.002 IN

APPLIED LOAD (lbs)	PHYSICAL CRACK LENGTH (in)	K <sub>r</sub> (UNCORRECTED) (psi /in)	EFFECTIVE CRACK LENGTH (in)	K <sub>r</sub> (CORRECTED) (psi /in)
820	1.514	39,692	1.553	40,712
840	1.514	40,660	1.555	41,761
860	1.516	41,677	1.559	42,867
880	1.519	42,754	1.565	44,046
900	1.519	43,726	1.567	45,113
920	1.524	44,843	1.575	46,348
940	1.524	45,818	1.577	47,430
960	1.525	46,811	1.580	48,537
1,000	1.525	48,762	1.585	50,730
1,020	1.526	49,786	1.590	51,892
1,040	1.526	50,762	1.593	53,005
1,060	1.526	51,738	1.595	54,125
1,080	1.529	52,786	1.601	55,336
1,120	1.529	54,741	1.607	57,616
1,140	1.532	55,832	1.613	58,902
1,160	1.534	56,893	1.619	60,164
1,180	1.534	57,874	1.622	61,338
1,180	1.534	57,874	1.622	61,338
1,200	1.534	58,854	1.626	62,520
1,220	1.541	60,117	1.638	64,063
1,260	1.544	62,210	1.648	66,648
1,280	1.546	63,272	1.654	67,979
1,300	1.546	64,260	1.659	69,228
1,320	1.548	65,321	1.665	70,584
1,340	1.562	66,926	1.686	72,682
1,380	1.562	68,923	1.695	75,318
1,400	1.571	70,341	1.711	77,245
1,420	1.575	71,552	1.722	78,913
1,440	1.578	72,679	1.730	80,485
1,460	1.578	73,689	1.735	81,907
1,468	FAILURE	---	---	---

TABLE P13

R-CURVE DATA FOR CW67 0.063 SHEET  
(SPECIMEN 35)  
McDonnell Aircraft Company

**SPECIMEN IDENTIFICATION:** 35  
**MATERIAL DESCRIPTION:** CW67 HIGH STRENGTH ALUMINUM SHEET  
**SPECIMEN TYPE:** C(T) (COMPACT SPECIMEN)  
**SPECIMEN ORIENTATION:** T-L  
**YIELD STRENGTH:** 82.3 KSI  
**SPECIMEN THICKNESS:** 0.071 IN  
**SPECIMEN WIDTH:** 4.001 IN

APPLIED LOAD (lbs)	PHYSICAL CRACK LENGTH (in)	K <sub>r</sub> (UNCORRECTED) (psi /in)	EFFECTIVE CRACK LENGTH (in)	K <sub>r</sub> (CORRECTED) (psi /in)
800	1.501	38,420	1.537	39,340
860	1.505	41,420	1.548	42,585
880	1.505	42,383	1.550	43,636
900	1.505	43,346	1.552	44,692
920	1.505	44,310	1.555	45,753
940	1.507	45,320	1.559	46,871
960	1.507	46,284	1.561	47,943
980	1.507	47,248	1.563	49,021
1,000	1.509	48,260	1.568	50,158
1,020	1.509	49,225	1.570	51,248
1,040	1.514	50,363	1.579	52,544
1,060	1.517	51,449	1.585	53,788
1,080	1.517	52,419	1.588	54,906
1,100	1.521	53,526	1.595	56,191
1,120	1.521	54,499	1.598	57,328
1,140	1.521	55,472	1.602	58,471
1,160	1.521	56,445	1.605	59,623
1,180	1.523	57,482	1.610	60,860
1,200	1.523	58,456	1.613	62,031
1,220	1.523	59,430	1.617	63,210
1,240	1.523	60,405	1.620	64,398
1,260	1.643	66,427	1.765	72,199
1,280	1.643	67,482	1.770	73,588
1,300	1.643	68,536	1.775	74,994
1,320	1.650	69,917	1.789	76,881
1,340	1.665	71,679	1.813	79,365
1,360	1.665	72,749	1.818	80,873
1,380	1.671	74,137	1.832	82,893
1,388	FAILURE	---	---	---

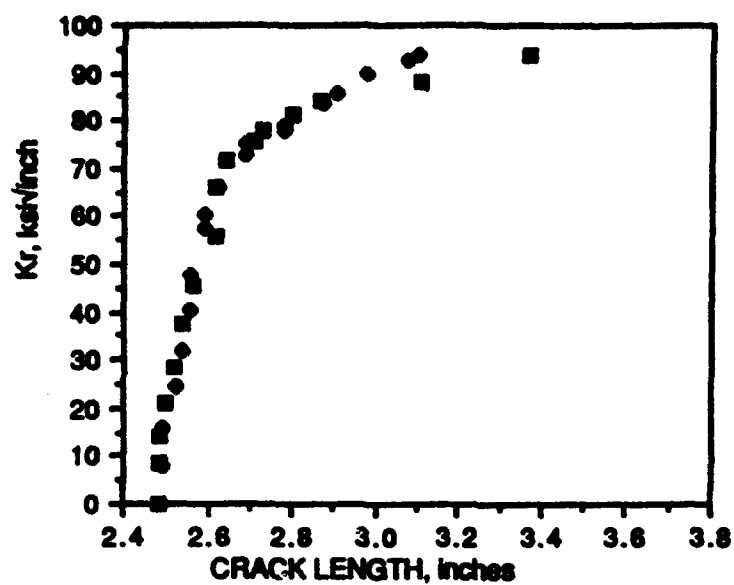


FIGURE P1. R-CURVE DATA for CW67 0.063 Inch Sheet (L-T Orientation).  
Martin Marietta.

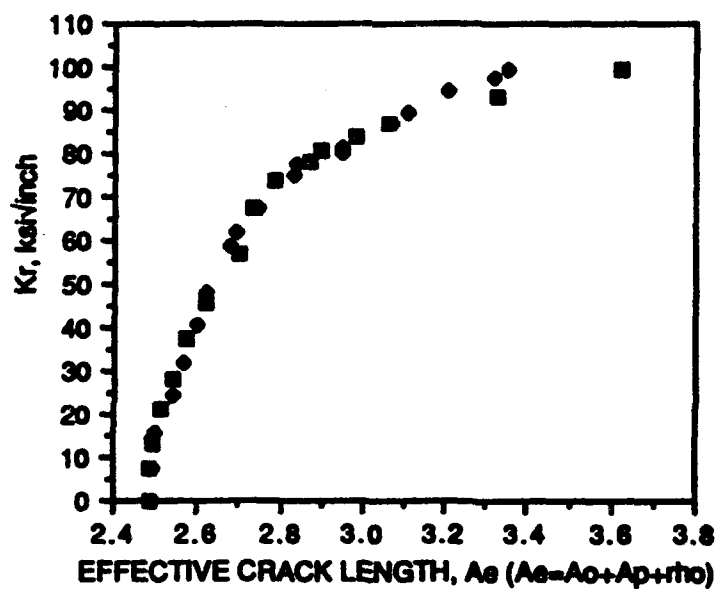


FIGURE P2. R-CURVE EFFECTIVE CRACK LENGTH ADJUSTED for PLASTIC ZONE  
(L-T Orientation).  
Martin Marietta.

TABLE P14  
R-CURVE DATA ASSOCIATED WITH FIGURES P1 AND P2  
(SPECIMEN 1)

Load, kips	Half Crack Length (a) inch	Half Crack Length, (a + rho) inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not Adjusted	Adjusted for Plasticity
0	2.485	2.485	0.0	0.0
2.50	2.485	2.487	8.3	7.8
4.25	2.485	2.490	14.1	13.2
6.40	2.500	2.512	21.3	21.4
8.45	2.520	2.541	28.3	28.4
11.10	2.535	2.571	37.3	37.6
13.35	2.565	2.619	45.2	45.8
16.30	2.615	2.698	55.9	56.9
19.25	2.615	2.733	66.1	67.7
20.75	2.645	2.785	71.8	73.8
21.50	2.710	2.866	75.6	77.9
22.15	2.710	2.893	78.1	80.7
22.60	2.800	2.982	81.2	84.0
23.00	2.865	3.060	83.9	87.0
22.85	3.105	3.327	88.3	92.9
22.90	3.365	3.620	94.0	99.5

Thickness = .058 inches  
Yield Strength = 78.6 ksi  
Specimen Width = 15.50 inches

TABLE P15  
R-CURVE DATA ASSOCIATED WITH FIGURES P1 and P2  
(SPECIMEN 2)

Load, kips	Half Crack Length (a), inch	Half Crack Length (a + rho), inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not Adjusted	Adjusted for Plasticity
0	2.490	2.490	0.0	0.0
2.8	2.490	2.492	8.2	7.7
5.4	2.490	2.496	15.8	15.8
8.2	2.525	2.540	24.2	24.3
10.8	2.535	2.562	31.9	32.1
13.5	2.555	2.597	40.1	40.5
16.0	2.555	2.615	47.5	48.1
19.3	2.590	2.680	57.4	58.9
20.2	2.590	2.688	60.5	61.8
21.8	2.625	2.742	65.9	67.5
23.7	2.685	2.829	72.7	74.9
24.4	2.685	2.839	74.9	77.2
24.7	2.780	2.945	77.6	80.1
25.1	2.780	2.951	78.9	81.5
26.1	2.870	3.065	83.8	86.9
26.5	2.905	3.109	85.8	89.1
27.2	2.975	3.205	89.6	94.4
27.4	3.075	3.321	92.4	97.7
27.6	3.100	3.353	93.6	99.1

Thickness = 0.066 inches  
Yield Strength = 78.6 ksi  
Specimen Width = 15.50 inches

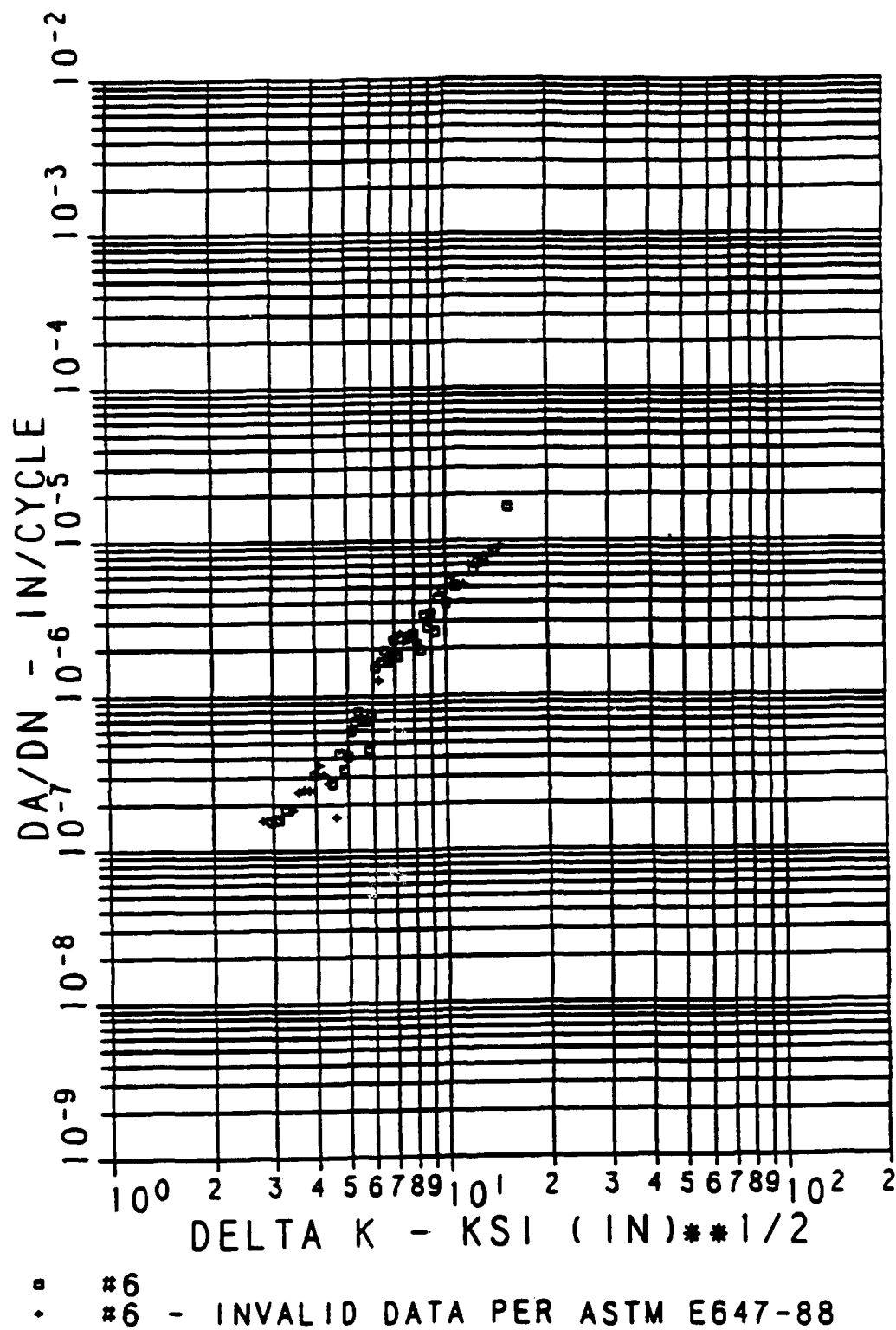
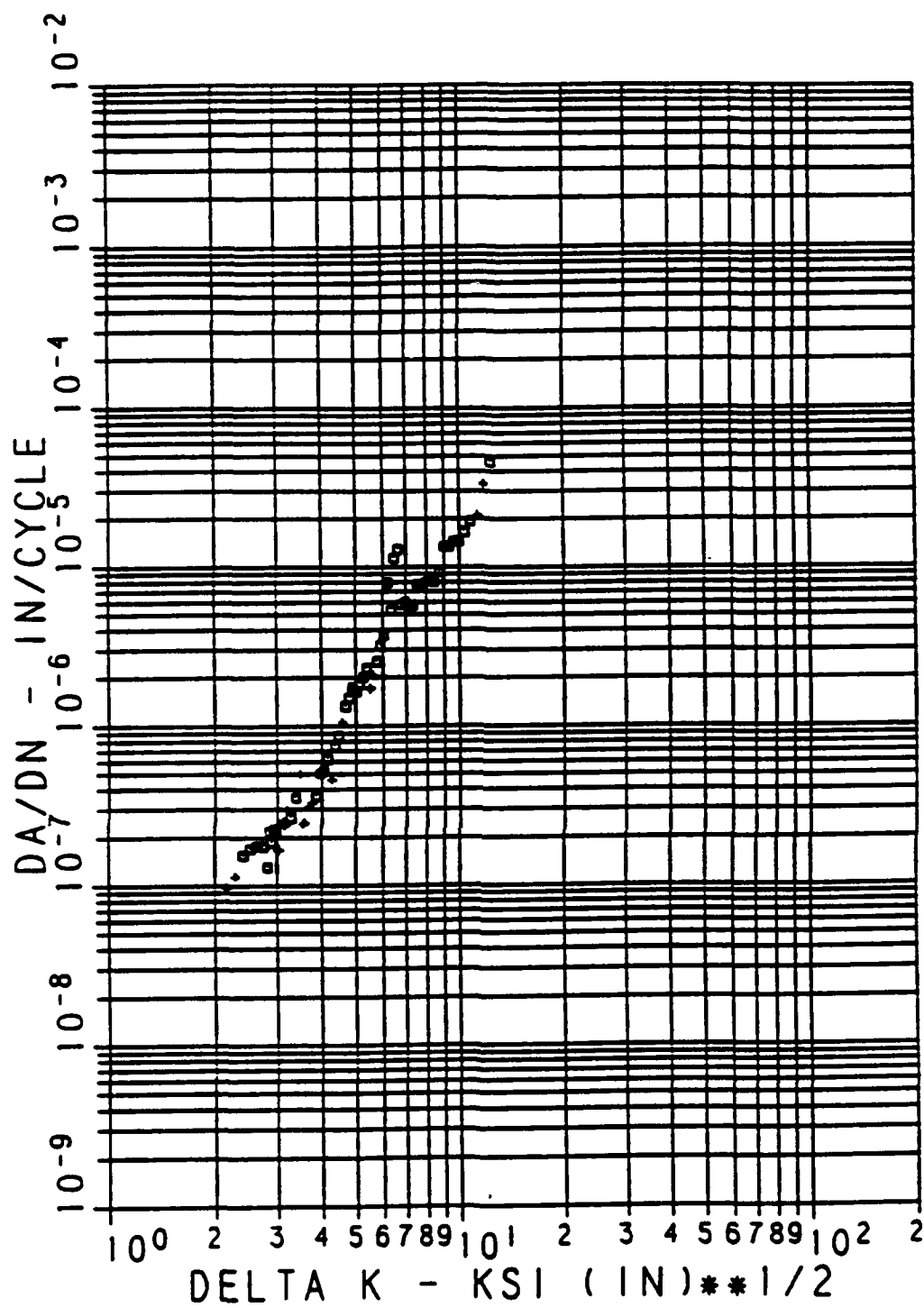
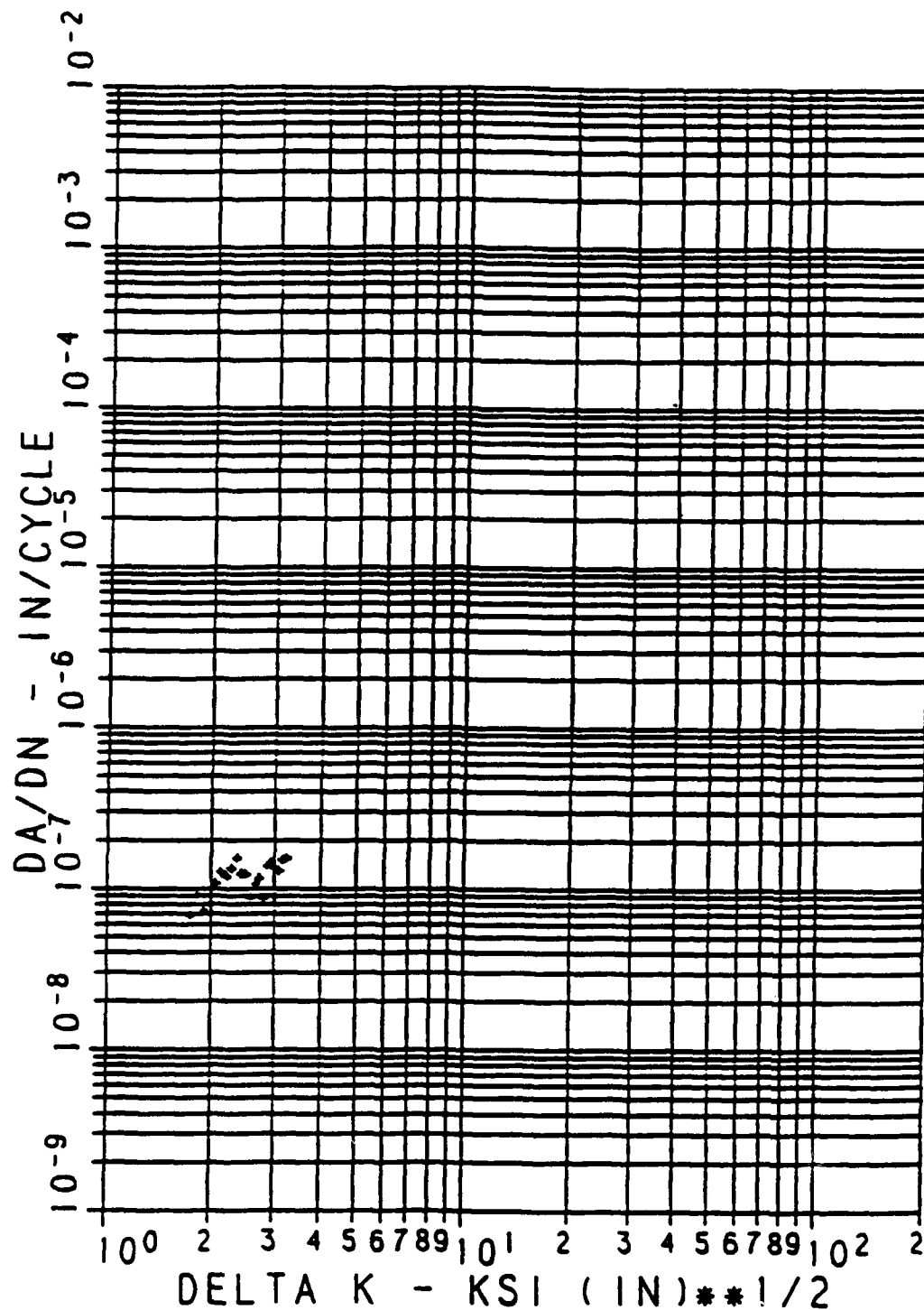


FIGURE P3. FATIGUE CRACK GROWTH RATE DATA for CW67 0.063 Sheet  
(L-T Orientation, R=0.1, Lab Air, Room Temperature and Specimen #6)  
McDonnell Aircraft Company.



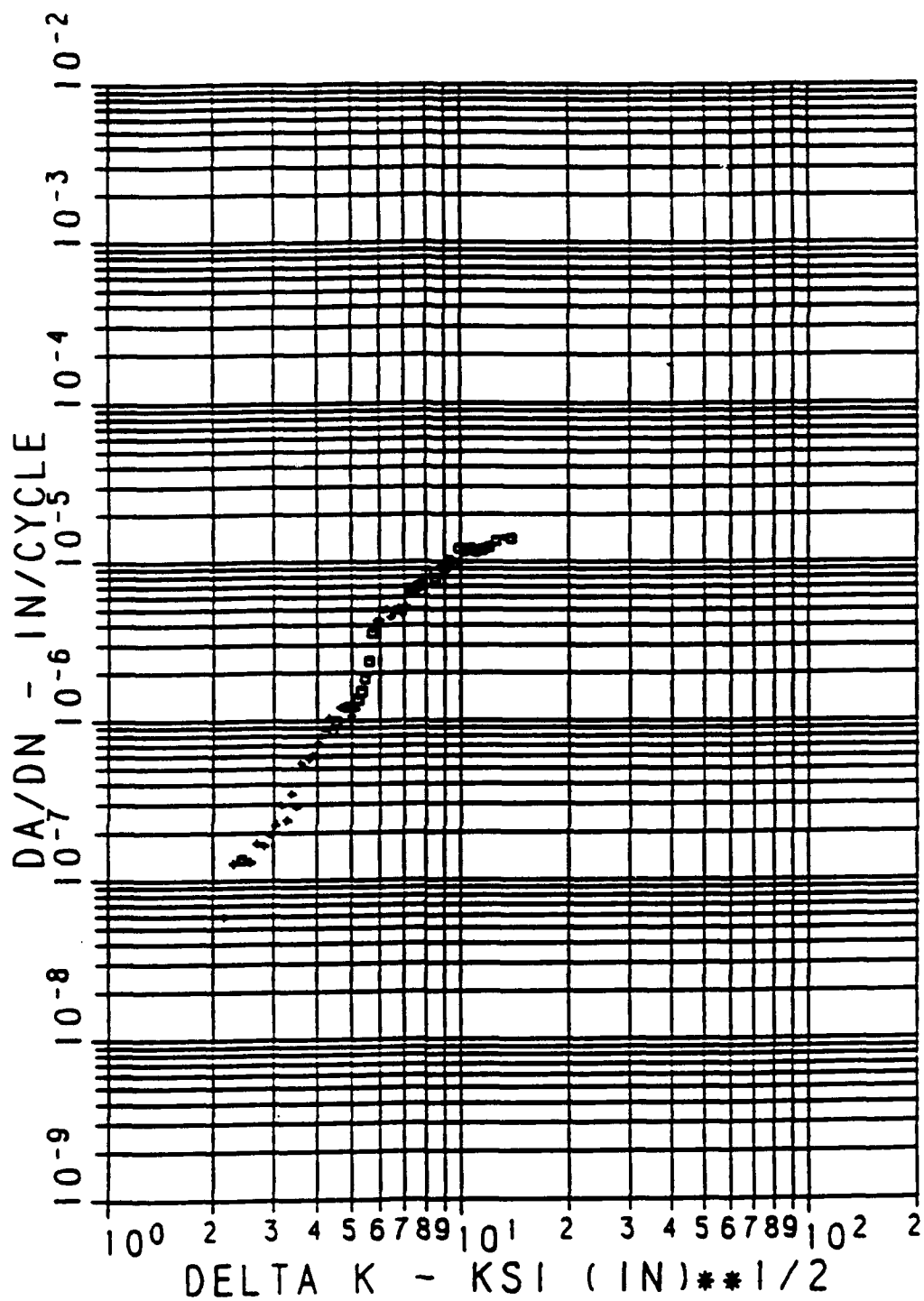
■ #7  
 • #7 - INVALID DATA PER ASTM E647-88

FIGURE P4. FATIGUE CRACK GROWTH RATE DATA for CW67 0.063 Sheet  
 (L-T Orientation, R=0.33, Lab Air, Room Temperature and Specimen #7).  
 McDonnell Aircraft Company.



■ #4  
 • #4 - INVALID DATA PER ASTM E647-88

FIGURE P5. FATIGUE CRACK GROWTH RATE DATA for CW67 0.063 Sheet  
 (T-L Orientation, R=0.1, Lab Air, Room Temperature and Specimen #4).  
 McDonnell Aircraft Company.



• #5  
 • #5 - INVALID DATA PER ASTM E647-88

FIGURE P6. FATIGUE CRACK GROWTH RATE DATA for CW67 0.063 " Sheet  
 (T-L Orientation, R=0.33, Lab Air, Room Temperature and Specimen #5).  
 McDonnell Aircraft Company.

## **APPENDIX Q**

### **CW67 PLATE 0.4"X16"X48"**

#### **INTRODUCTION**

The Alcoa P/M aluminum alloy CW67 0.4 inch plates were received April 1989. Only Martin Marietta tested the CW67 plate.

#### **TESTING**

Tensile and toughness tests were generated according to ASTM standards, unless otherwise specified.

TABLE Q1

## TENSILE RESULTS FOR ALCOA

CW67 PLATE (0.4" X 16" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	RT	LONG	81.8	79.1	11.0	18.1	9.8
MARIETTA, LOUISIANA			81.1	77.2	13.0	23.1	9.8
			82.0	78.4	12.5	24.7	9.9
		AVERAGE	81.6	78.2	12.2	22.0	9.8
		STANDARD DEVIATION	0.5	1.0	1.0	3.4	0.1

TABLE Q2

## TENSILE RESULTS FOR ALCOA

CW67 PLATE (0.4" X 16" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	RT	L TRANS	88.8	84.6	6.0	5.6	9.9
MARIETTA, LOUISIANA			87.8	83.8	6.0	6.1	10.3
			86.9	83.6	6.5	6.6	10.1
		AVERAGE	87.8	84.0	6.2	6.1	10.1
		STANDARD DEVIATION	1.0	0.5	0.3	0.5	0.2

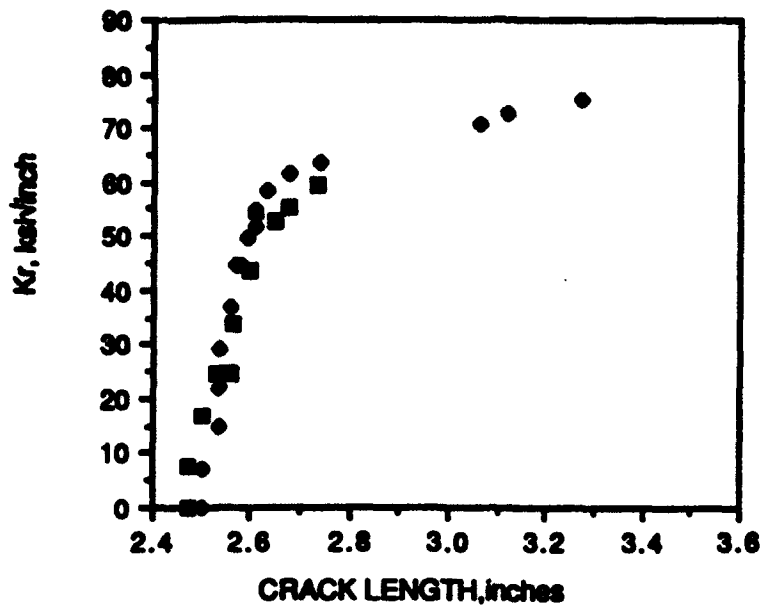


FIGURE Q1. R-CURVE DATA for CW67 0.4 INCH PLATE (L-T ORIENTATION).  
Martin Marietta.

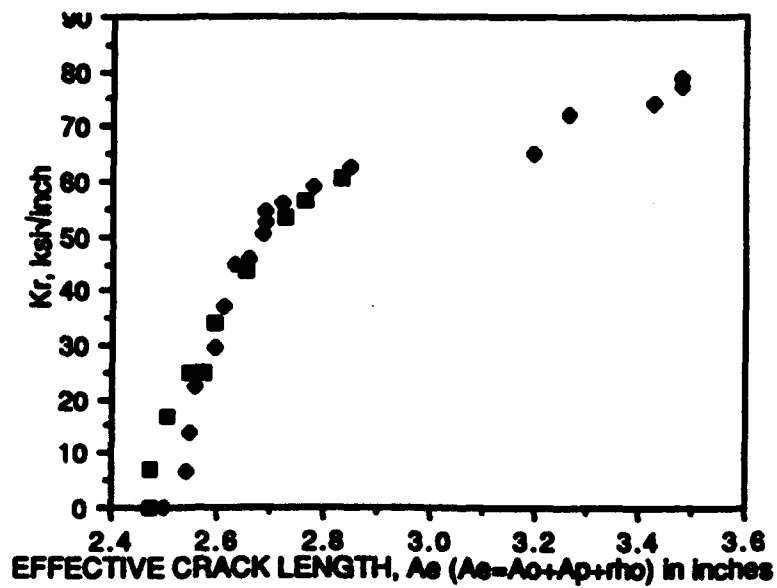


FIGURE Q2. R-CURVE EFFECTIVE CRACK LENGTH ADJUSTED for Plastic Zone  
Data for CW67 0.4 Inch Plate (L-T Orientation).  
Martin Marietta.

**TABLE Q3**  
**R-CURVE DATA ASSOCIATED WITH FIGURES Q1 AND Q2**  
**(SPECIMEN 1)**

Load, kips	Half Crack Length (a), inch	Half Crack Length (a + rho), inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not Adjusted	Adjusted for Plasticity
0	2.475	2.475	0.0	0.0
16.1	2.475	2.476	7.8	7.3
34.3	2.500	2.507	16.8	16.8
50.2	2.503	2.546	24.7	24.8
50.2	2.506	2.576	24.7	25.0
68.5	2.507	2.596	34.0	34.3
86.6	2.600	2.650	43.4	43.9
103.4	2.650	2.724	52.5	53.3
108.0	2.680	2.762	55.2	56.2
114.8	2.735	2.831	59.2	60.7

Thickness = 0.396 inches  
Yield Strength = 78.2 ksi  
Specimen Width = 15.49 inches

**TABLE Q4**  
**R-CURVE DATA ASSOCIATED WITH FIGURES Q1 and Q2**  
**(SPECIMEN 2)**

Load, kips	Half Crack Length (a), inch	Half Crack Length (a + rho), inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not Adjusted	Adjusted for Plasticity
0	2.500	2.501	0.0	0.0
15.0	2.500	2.540	7.3	6.8
29.9	2.535	2.548	14.6	13.6
45.5	2.535	2.558	22.2	22.3
60.1	2.535	2.596	29.3	29.5
75.2	2.560	2.609	36.9	37.2
90.3	2.570	2.634	44.4	44.8
91.5	2.580	2.656	44.4	45.7
100.6	2.590	2.682	49.8	50.5
104.3	2.610	2.688	51.8	52.6
108.1	2.610	2.691	53.7	54.6
110.5	2.610	2.721	54.9	55.9
116.3	2.630	2.777	58.1	59.2
121.1	2.675	2.850	61.2	62.4
123.8	2.740	3.196	63.6	65.0
127.1	3.060	3.264	70.5	72.2
129.0	3.120	3.425	72.5	74.4
129.0	3.270	3.481	75.1	77.1
129.8	3.320	3.481	76.5	78.6

Thickness = 0.396 inches  
Yield Strength = 78.2 ksi  
Specimen Width = 15.50 inches

**APPENDIX R**  
**CW67 EXTRUSION**  
**1.5"x4.5"x36"**

**INTRODUCTION**

The Alcoa P/M aluminum alloy 1.5"x4.5"x36" extrusions were received August 1987. LTV, McDonnell Aircraft Company and the Air Force tested the CW67 extrusion material.

**TESTING**

Mechanical properties (tension, compression, shear, bearing, and fracture toughness), and constant amplitude fatigue crack growth tests were generated according to ASTM standards, unless otherwise specified.

Spectrum fatigue crack growth rate tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

TABLE R1  
TENSILE RESULTS FOR  
ALCOA CW67 EXTRUSION

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
LTV	RT	LONG	86.4	81.3	10.5		10.2
			85.9	81.3	11.4		10.0
			85.9	81.3	12.3		9.9
			85.5	78.6	12.3		9.4
			86.1	80.4	11.7		9.5
AIR FORCE	RT	LONG	89.1	84.9	10.0	28.0	
			86.2	81.5	9.5	27.0	
			85.5	80.6	15.2	28.7	
MCAIR	RT	LONG	86.0	81.5	10.0	35.0	14.3
			83.0	79.0	14.0	38.0	13.4
			82.5	77.5	12.0	36.0	13.7
		AVERAGE	85.6	80.7	11.7	32.1	11.3
		STANDARD DEVIATION	1.7	1.9	1.7	4.7	2.1

TABLE R2  
TENSILE RESULTS FOR  
ALCOA CW67 EXTRUSION

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)			
LTV	RT	L TRANS	80.9	75.0	10.0		10.0			
			81.0	75.0	12.0		11.1			
			81.6	71.0	11.2		12.9			
			80.9	72.3	9.1		11.0			
			80.9		10.9		12.9			
AIR FORCE	RT	L TRANS	82.5	77.4	10.0	26.0				
			83.1	78.2	10.7	35.0				
			82.3	76.7	8.4	20.4				
MCAIR	RT	L TRANS	81.5	76.5	12.0	32.0	14.0			
			81.0	72.0	10.0	27.0	14.0			
			81.5	76.0	15.0	35.0	13.6			
			AVERAGE			81.6	75.0	10.8	29.2	12.4
			STANDARD DEVIATION			0.8	2.5	1.8	5.8	1.5

**TABLE R3**  
**COMPRESSION RESULTS FOR**  
**ALCOA CW67 EXTRUSION**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCAIR	RT	LONG	78.5	10.8
			80.0	10.9
			79.5	11.0
		AVERAGE	79.3	10.9
		STANDARD DEVIATION	0.8	0.1

**TABLE R4**  
**COMPRESSION RESULTS FOR**  
**ALCOA CW67 EXTRUSION**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCAIR	RT	L TRANS	80.0	11.2
			74.0	10.8
			79.0	10.8
		AVERAGE	77.7	10.9
		STANDARD DEVIATION	3.2	0.2

**TABLE R5**  
**IOSIPESCU SHEAR RESULTS FOR**  
**ALCOA CW67 EXTRUSION**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<hr/>		
<b>LTV</b>	<b>LONG</b>	<b>49.8</b>
		<b>50.0</b>
		<b>49.9</b>
		<b>48.1</b>
		<b>48.7</b>
		<b>50.7</b>
	<b>AVERAGE</b>	<b>49.5</b>
	<b>STANDARD DEVIATION</b>	<b>1.0</b>

**TABLE R6**  
**IOSIPESCU SHEAR RESULTS FOR**  
**ALCOA CW67 EXTRUSION**

<b>COMPANY</b>	<b>ORIENTATION</b>	<b>SHEAR STRENGTH (KSI)</b>
<hr/>		
<b>LTV</b>	<b>L TRANS</b>	<b>51.5</b>
		<b>51.2</b>
		<b>51.5</b>
		<b>48.9</b>
		<b>48.6</b>
		<b>51.0</b>
	<b>AVERAGE</b>	<b>50.5</b>
	<b>STANDARD DEVIATION</b>	<b>1.3</b>

**TABLE R7**  
**AMSLER DOUBLE SHEAR RESULTS FOR**  
**ALCOA CW67 EXTRUSION**

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
<hr/>		
MCAIR	L - S	52.1
		48.3
		48.5
	AVERAGE	49.6
	STANDARD DEVIATION	2.1

**TABLE R8**  
**BEARING RESULTS FOR**  
**ALCOA CW67 EXTRUSION**

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
LTV	LONG	1.5		124.0		103.0
				123.0		104.0
				126.0		106.0
MCAIR	LONG	1.5		126.9		112.1
				122.9		107.2
AVERAGE				124.6		106.5
STANDARD DEVIATION				1.8		3.6

**TABLE R9**  
**BEARING RESULTS FOR**  
**ALCOA CW67 EXTRUSION**

COMPANY	ORIENTATION	e/D	BEARING		BEARING	
			ULT.	STR.	YIELD	STR.
			(KSI)		(KSI)	
LTV	L TRANS	1.5		122.0		109.0
				123.0		108.0
				129.0		112.0
MCAIR	L TRANS	1.5		123.7		107.4
				121.7		105.7
AVERAGE				123.9		108.4
STANDARD DEVIATION				3.0		2.3

**TABLE R10**  
**BEARING RESULTS FOR**  
**ALCOA CW67 EXTRUSION**

COMPANY	ORIENTATION	e/D	BEARING		BEARING
			ULT.	STR.	YIELD STR.
			(KSI)		(KSI)
LTV	LONG	2.0		158.0	118.0
				155.0	126.0
				156.0	121.0
MCAIR	LONG	2.0		174.2	144.4
				171.0	139.0
AVERAGE				162.8	129.7
STANDARD DEVIATION				9.0	11.5

**TABLE R11**  
**BEARING RESULTS FOR**  
**ALCOA CW67 EXTRUSION**

COMPANY	ORIENTATION	e/D	BEARING		BEARING
			ULT.	STR.	YIELD STR.
			(KSI)		(KSI)
LTV	L TRANS	2.0		153.0	122.0
				162.0	129.0
				156.0	124.0
MCAIR	L TRANS	2.0		170.7	141.3
				171.1	140.5
AVERAGE				162.6	131.4
STANDARD DEVIATION				8.3	9.1

**TABLE R12**  
**FRACTURE TOUGHNESS RESULTS FOR**  
**ALCOA CW67 EXTRUSION**

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
-----				
LTV	L-T	24.1		VALID
		22.4		VALID
		21.7		VALID
AIR FORCE	L-T	45.3		VALID
		46.9		VALID
		44.1		VALID
MCAIR	L-T	29.4		VALID
		29.0		VALID
	AVERAGE	32.9		
	STANDARD DEVIATION	10.8		

**TABLE R13**  
**FRACTURE TOUGHNESS RESULTS FOR**  
**ALCOA CW67 EXTRUSION**

COMPANY	ORIENTATION	KIC (KSI in <sup>0.5</sup> )	Kq (KSI in <sup>0.5</sup> )	COMMENT
<hr/>				
LTV	T-L		38.5	(1)
			36.1	(1)
			42.2	(1)
AIR FORCE	T-L	26.7		VALID
		27.2		VALID
MCAIR	T-L	18.5		VALID
		18.8		VALID
	AVERAGE	22.8	38.9	
	STANDARD DEVIATION	4.8	3.1	

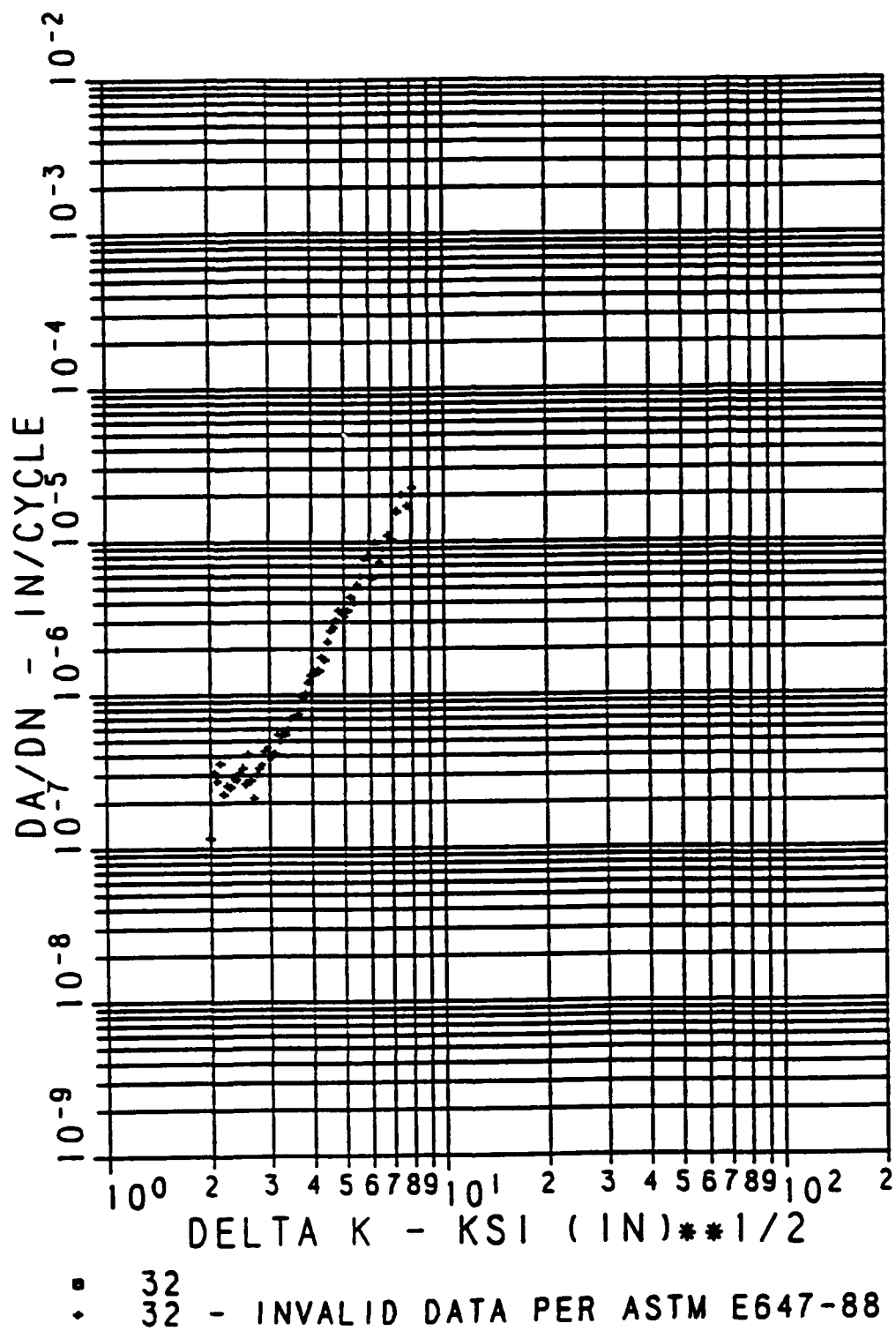
(1): INVALID DUE TO UNSYMMETRIC CRACK FRONT CURVATURE

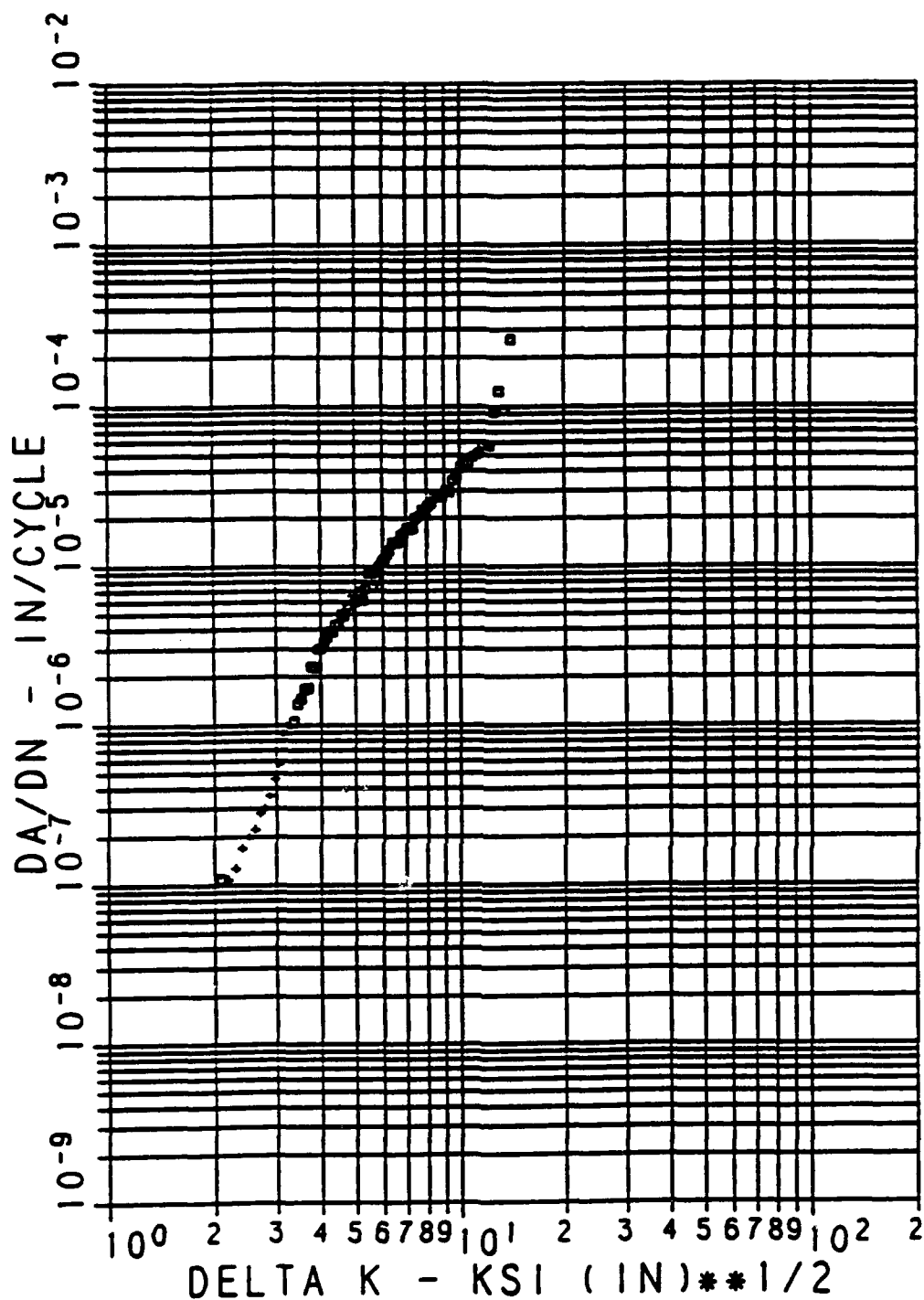
**TABLE R14**  
**FRACTURE TOUGHNESS RESULTS FOR**  
**ALCOA CW67 EXTRUSION**

COMPANY	ORIENTATION	KIC	Kq	COMMENT
		(KSI in <sup>-0.5</sup> )	(KSI in <sup>-0.5</sup> )	
MCAIR	S-T	20.5		VALID
		21.2		VALID
	AVERAGE	20.9		
	STANDARD DEVIATION	0.5		

**TABLE R15**  
**FRACTURE TOUGHNESS RESULTS FOR**  
**ALCOA CW67 EXTRUSION**

COMPANY	ORIENTATION	KIC	Kq	COMMENT
		(KSI in <sup>-0.5</sup> )	(KSI in <sup>-0.5</sup> )	
MCAIR	S-L	33.0		VALID
	AVERAGE	33.0		
	STANDARD DEVIATION	0.0		





■ 33  
 • 33 - INVALID DATA PER ASTM E647-88

FIGURE R2. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion (L-T Orientation, R=0.33, Lab Air and Room Temperature). McDonnell Aircraft Company.

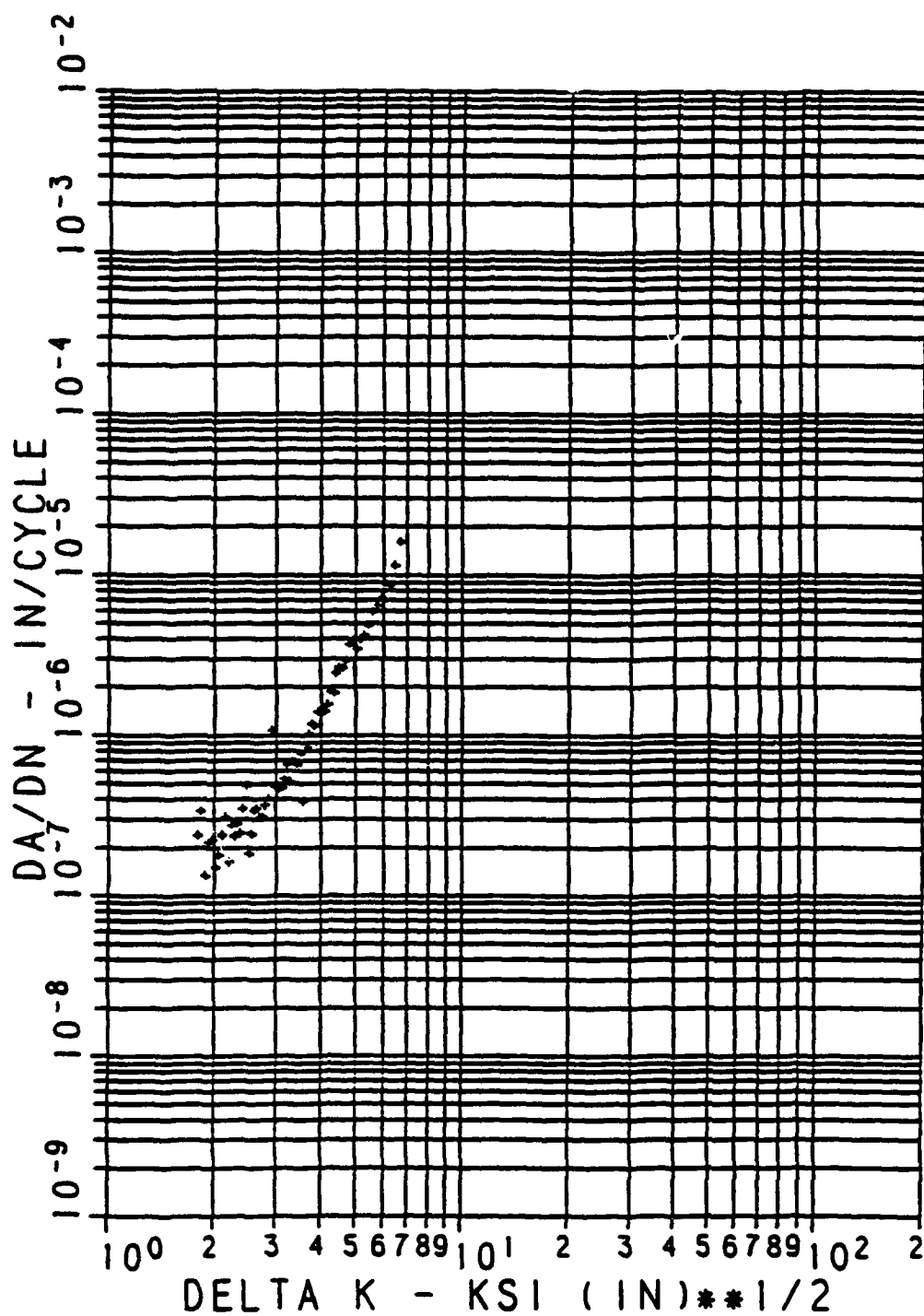


FIGURE R3. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion (T-L Orientation, R=0.1, Lab Air and Room Temperature). McDonnell Aircraft Company.

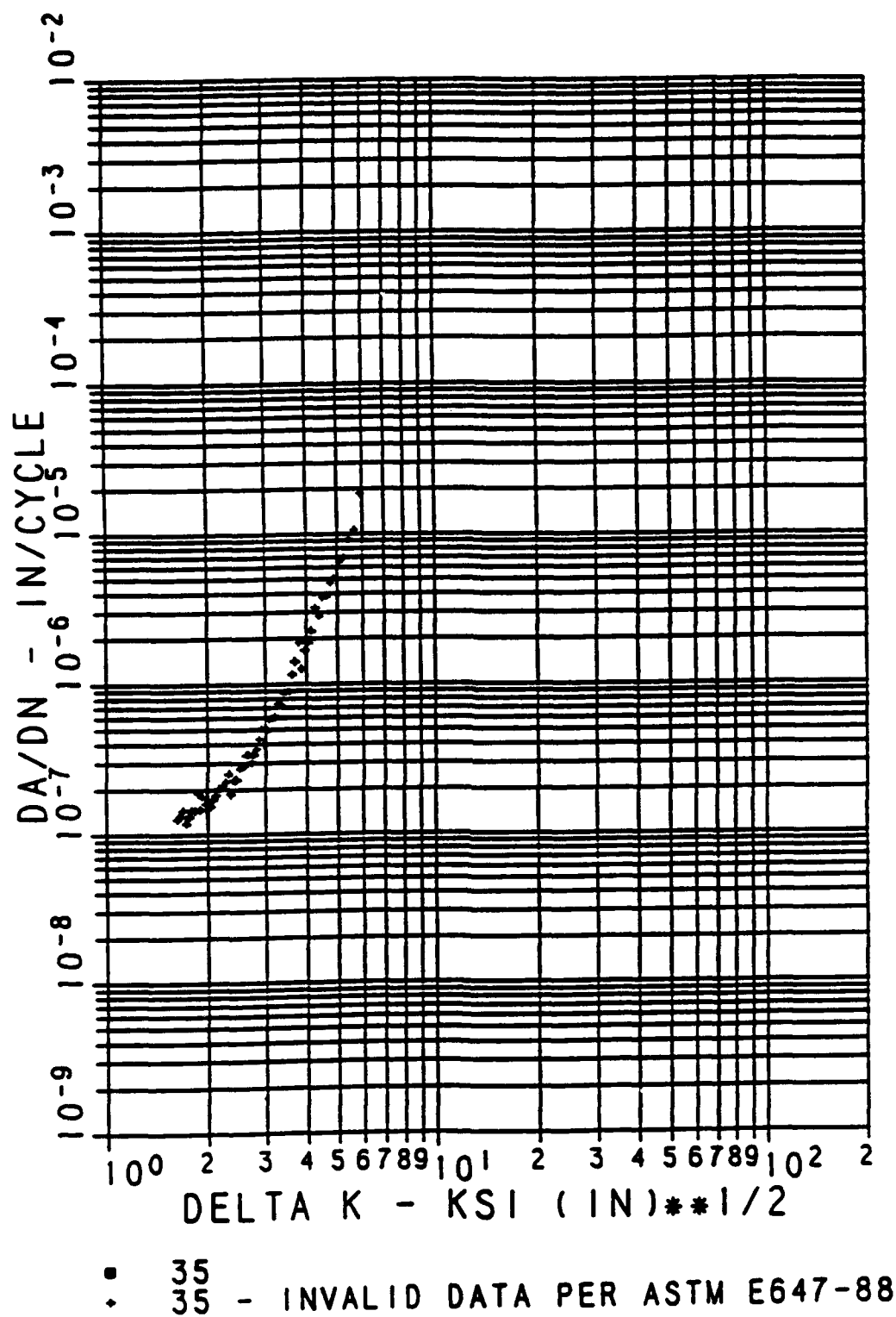


FIGURE R4. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion  
 (T-L Orientation,  $R=0.33$ , Lab Air and Room Temperature).  
 McDonnell Aircraft Company.

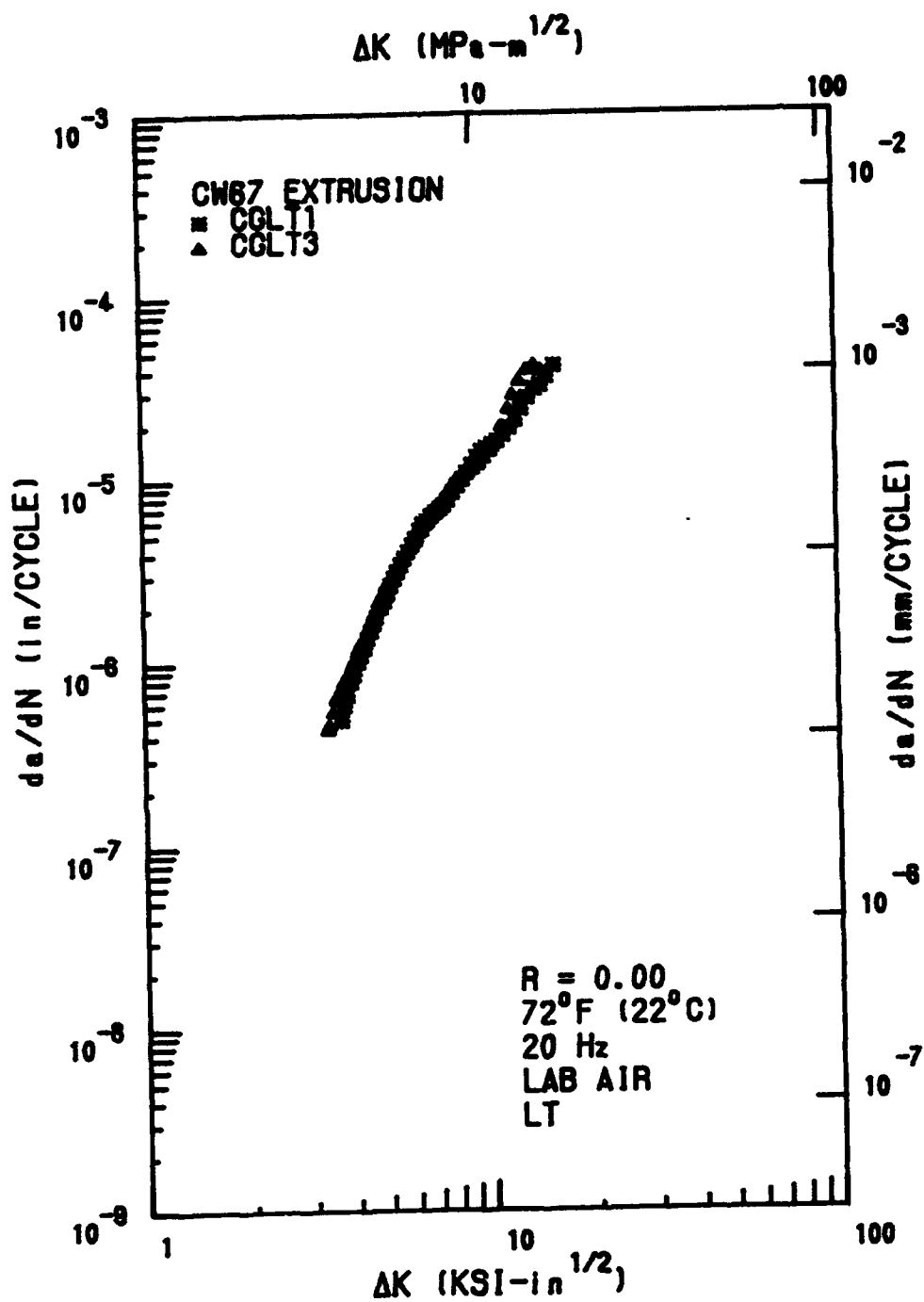


FIGURE R5. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion  
 (L-T Orientation).  
 Air Force.

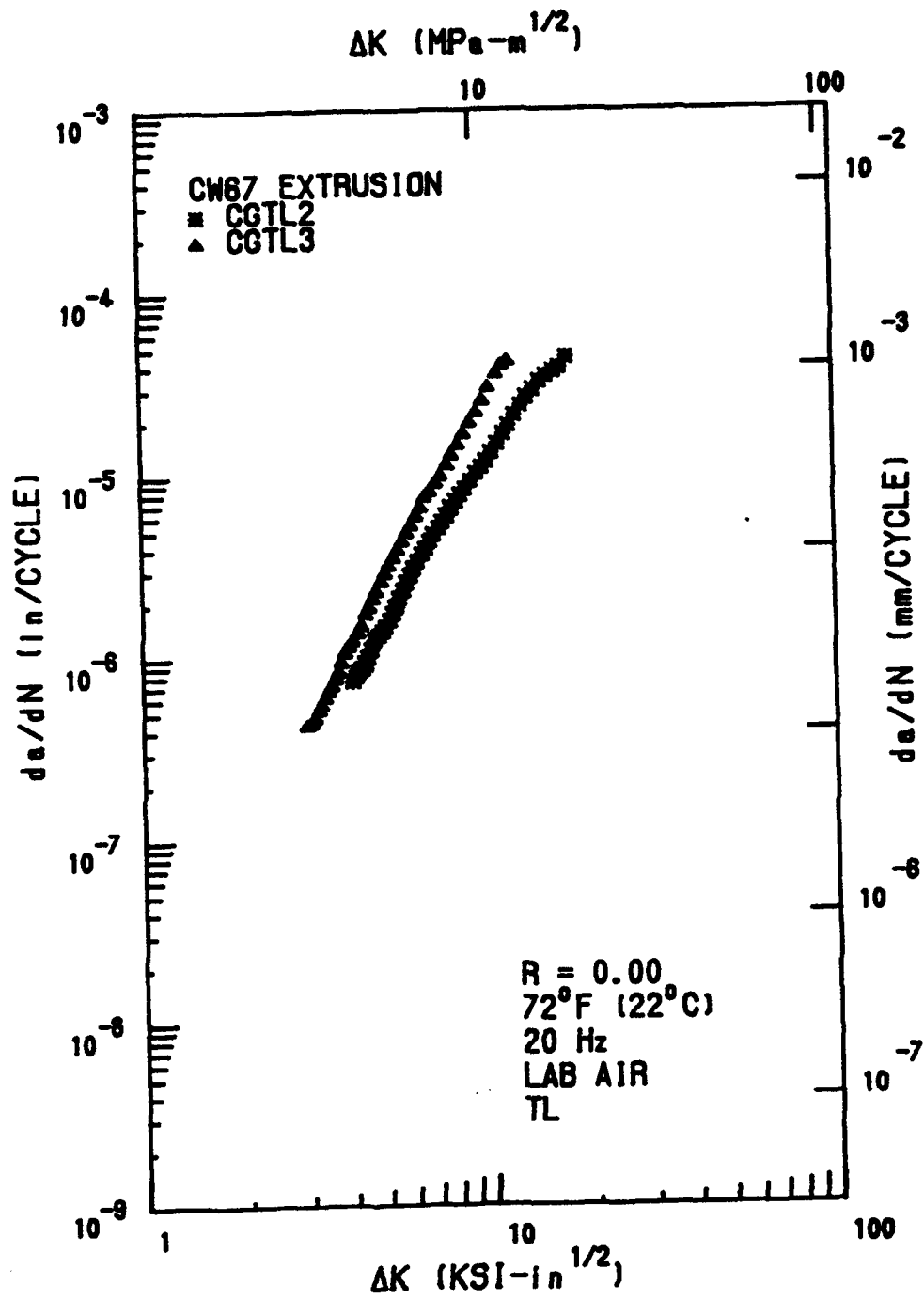


FIGURE R6. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion  
 (T-L Orientation).  
 Air Force.

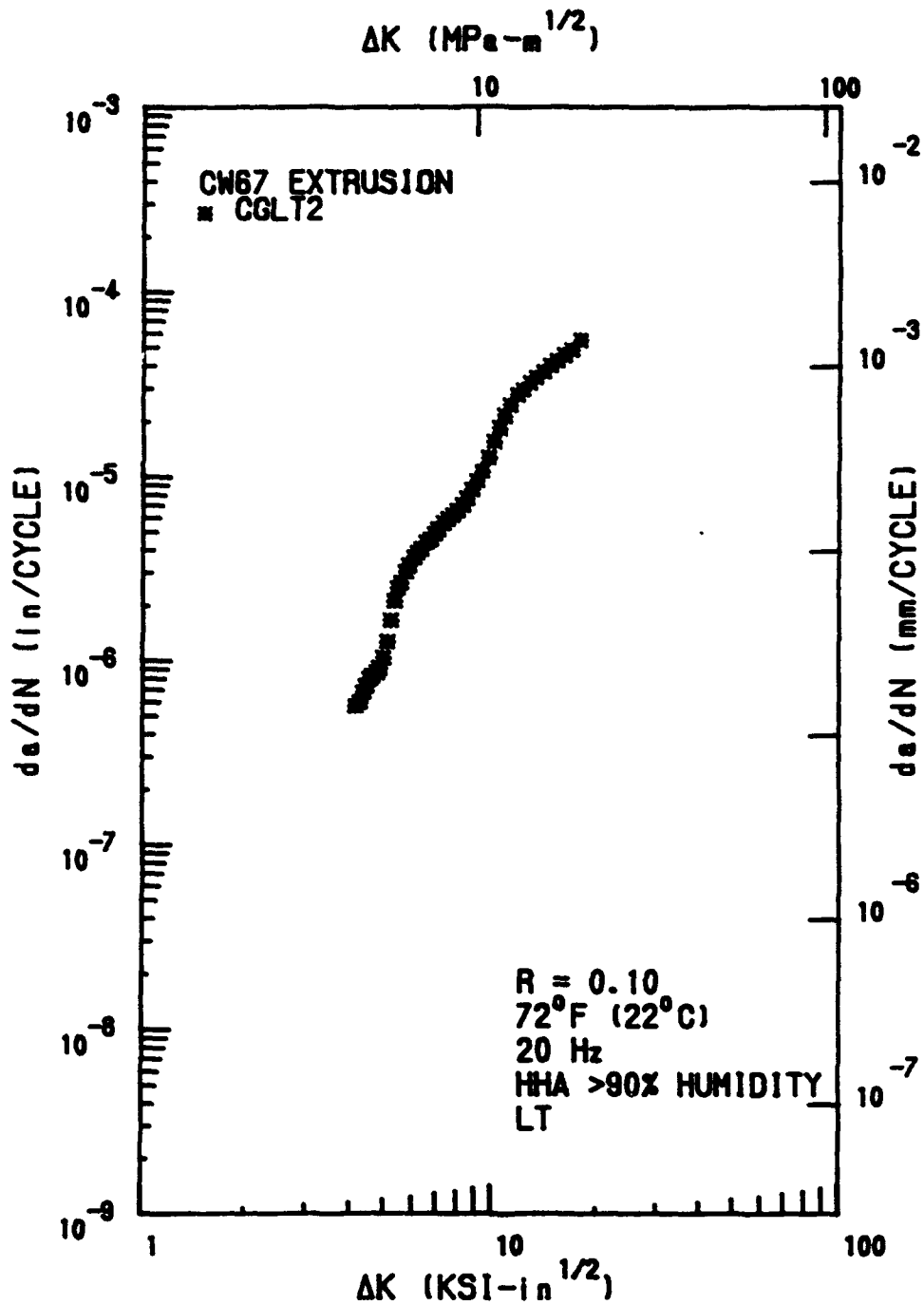


FIGURE R7. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion  
 (L-T Orientation and High Humidity).  
 Air Force.

SPECIMEN GLT-1

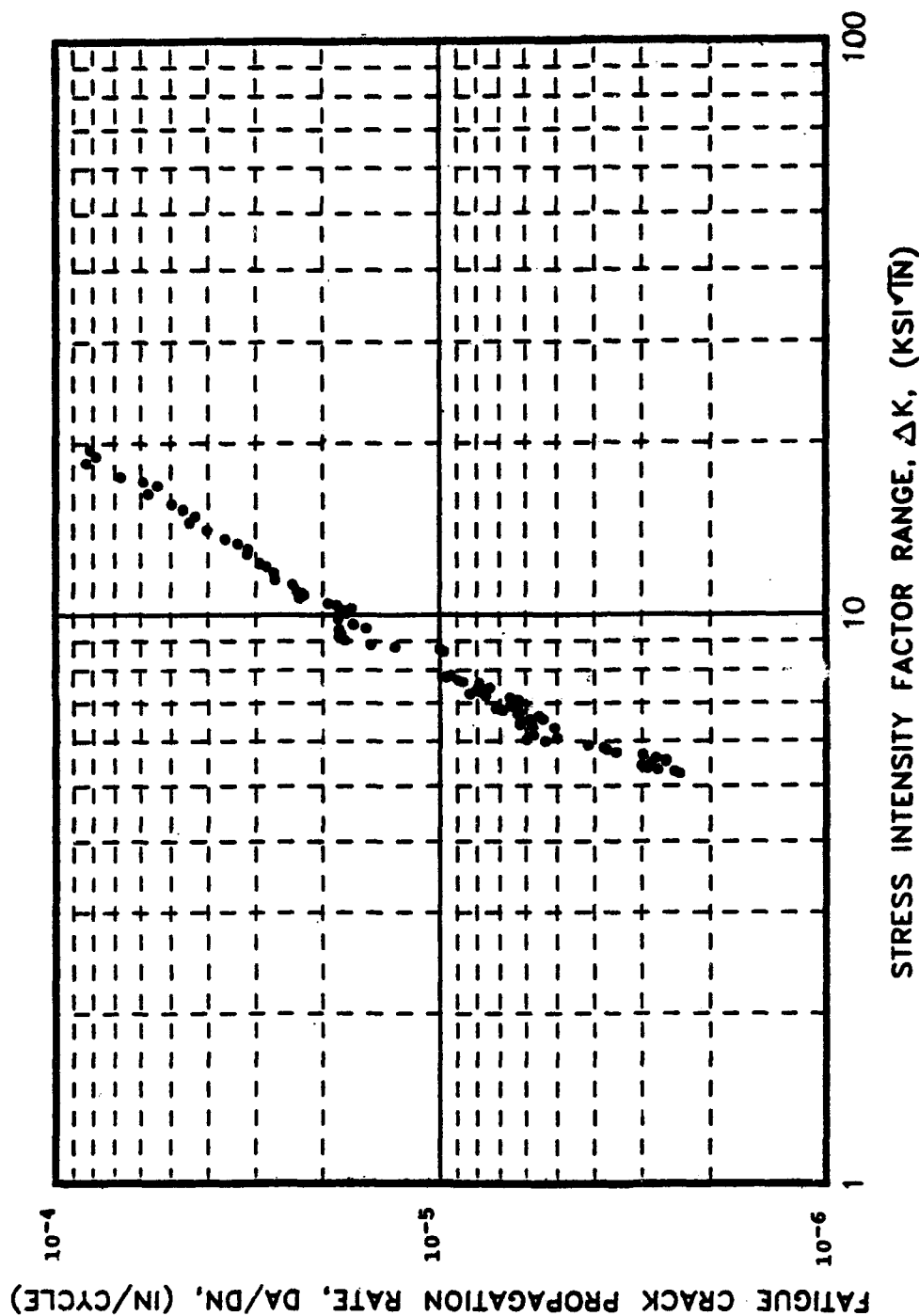


FIGURE R8. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion. (L-T Orientation, Specimen GLT-1).  
LTV.

SPECIMEN GLT-2

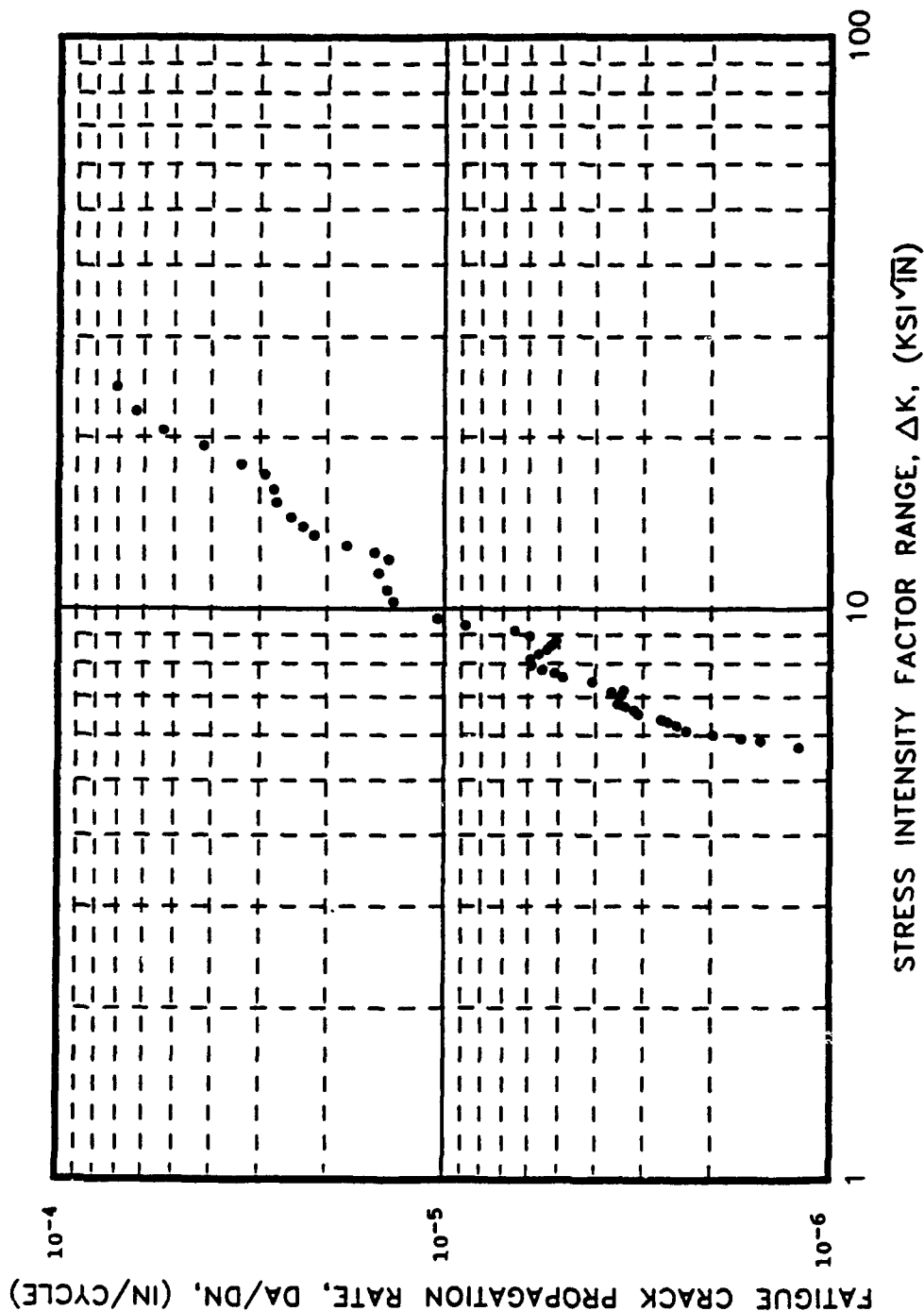


FIGURE R9. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion (L-T Orientation, Specimen GLT-2). LTV.

SPECIMEN GLT-3

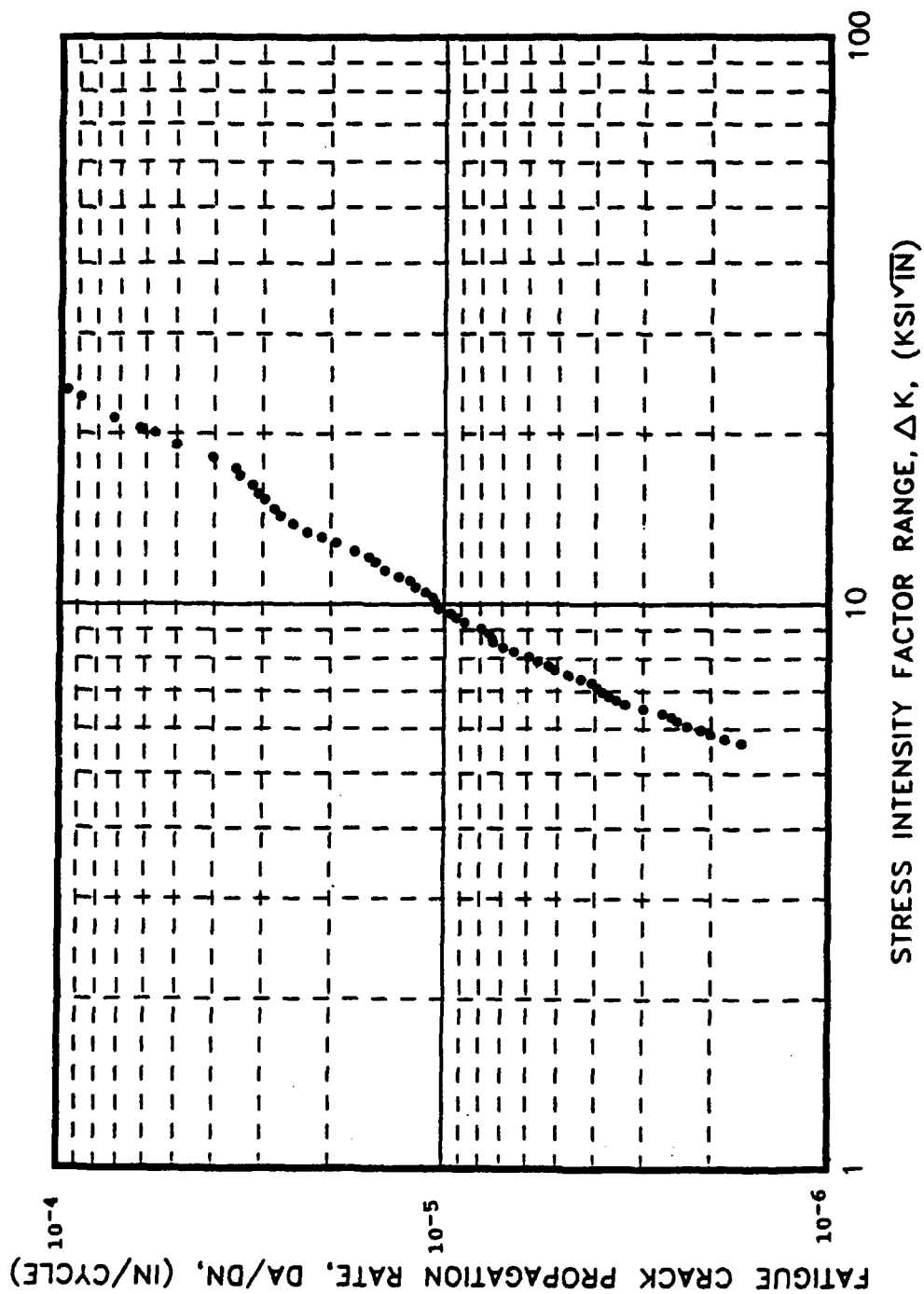


FIGURE R10. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion, Specimen GLT-3).  
LTV.

SPECIMEN GTL-1

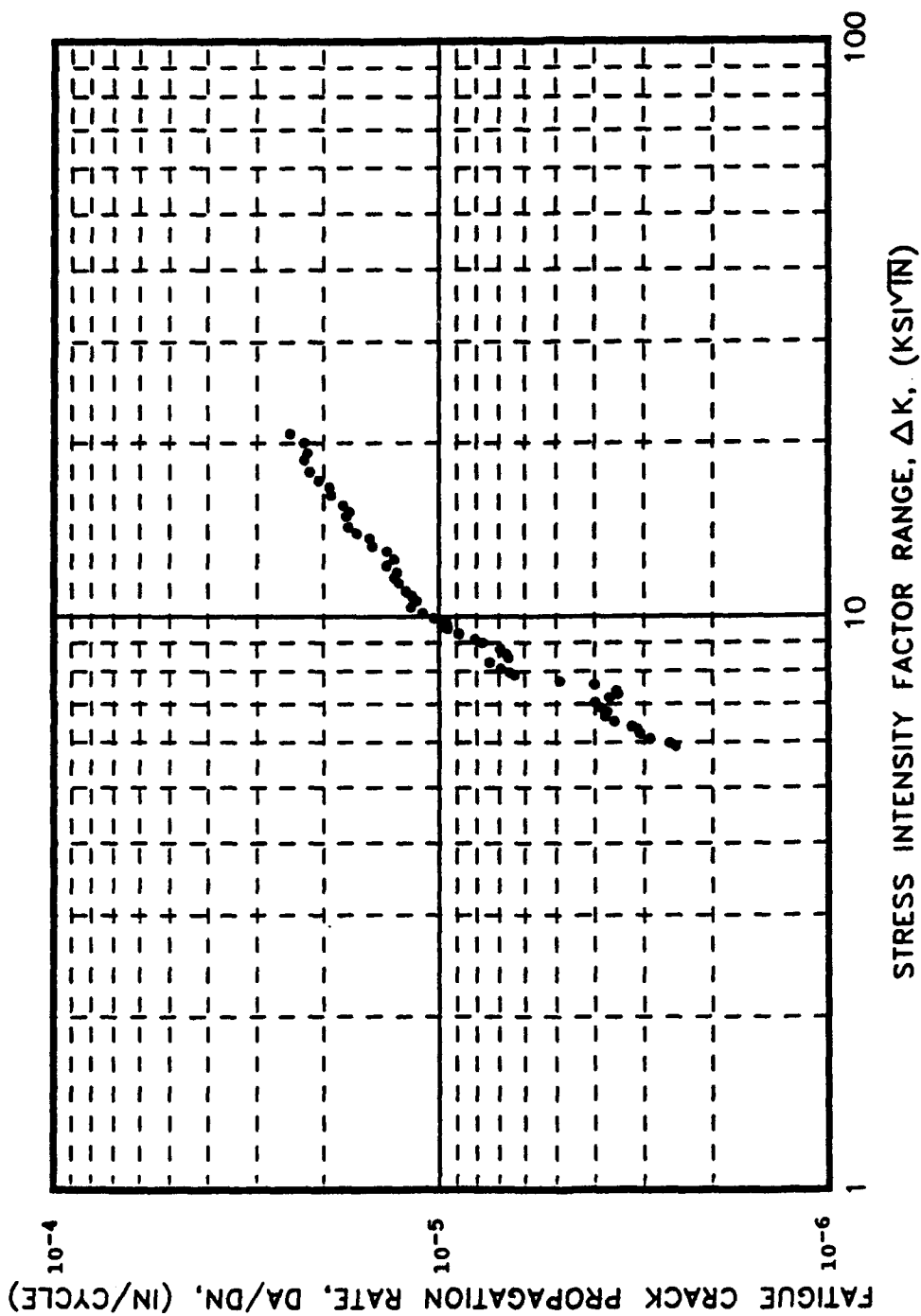


FIGURE R11. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion. (T-L Orientation, Specimen GTL-1).  
LTV.

SPECIMEN GTL-2

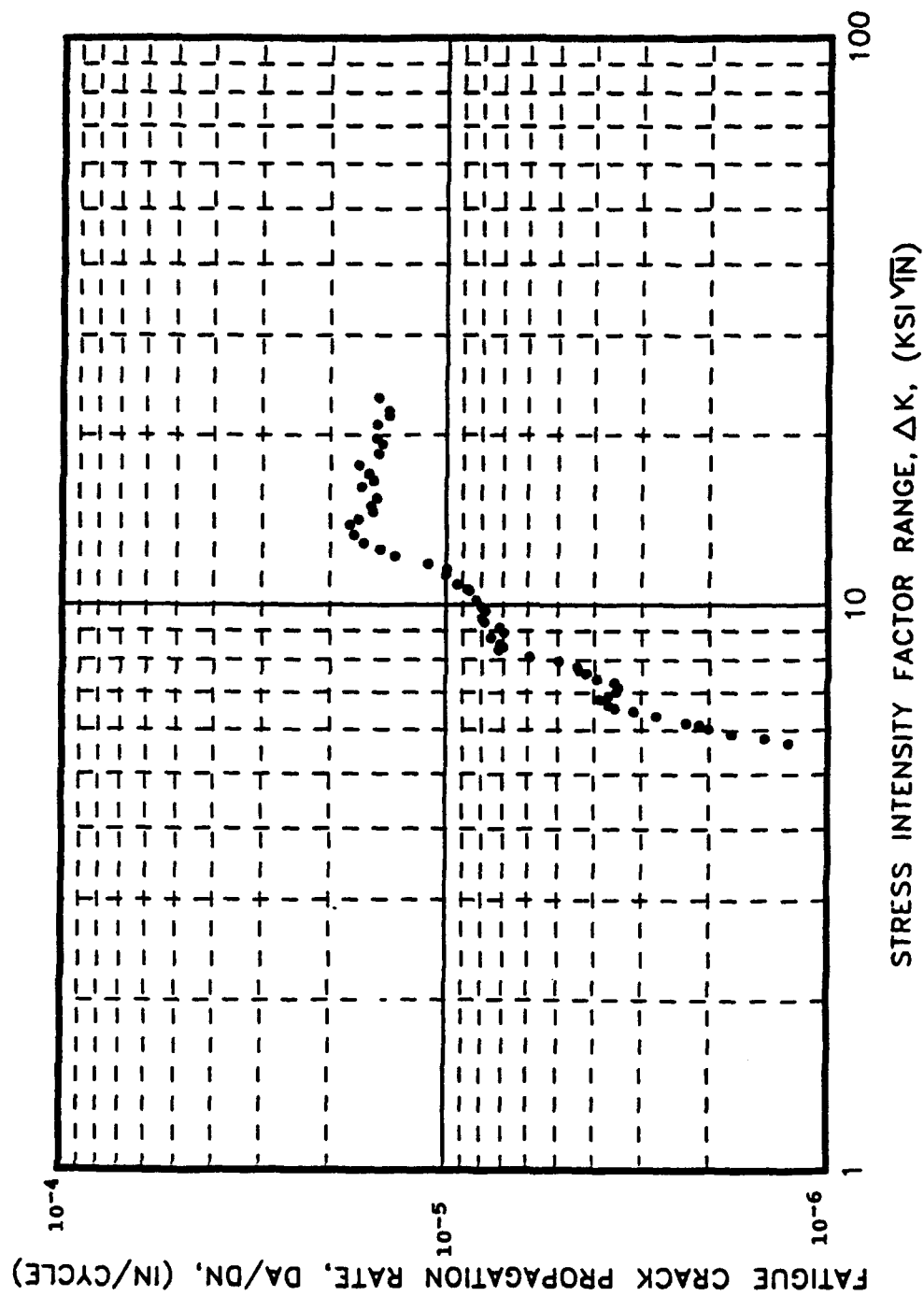


FIGURE R12. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion. (T-L Orientation, Specimen GTL-2).  
LTV.

SPECIMEN GTL-3

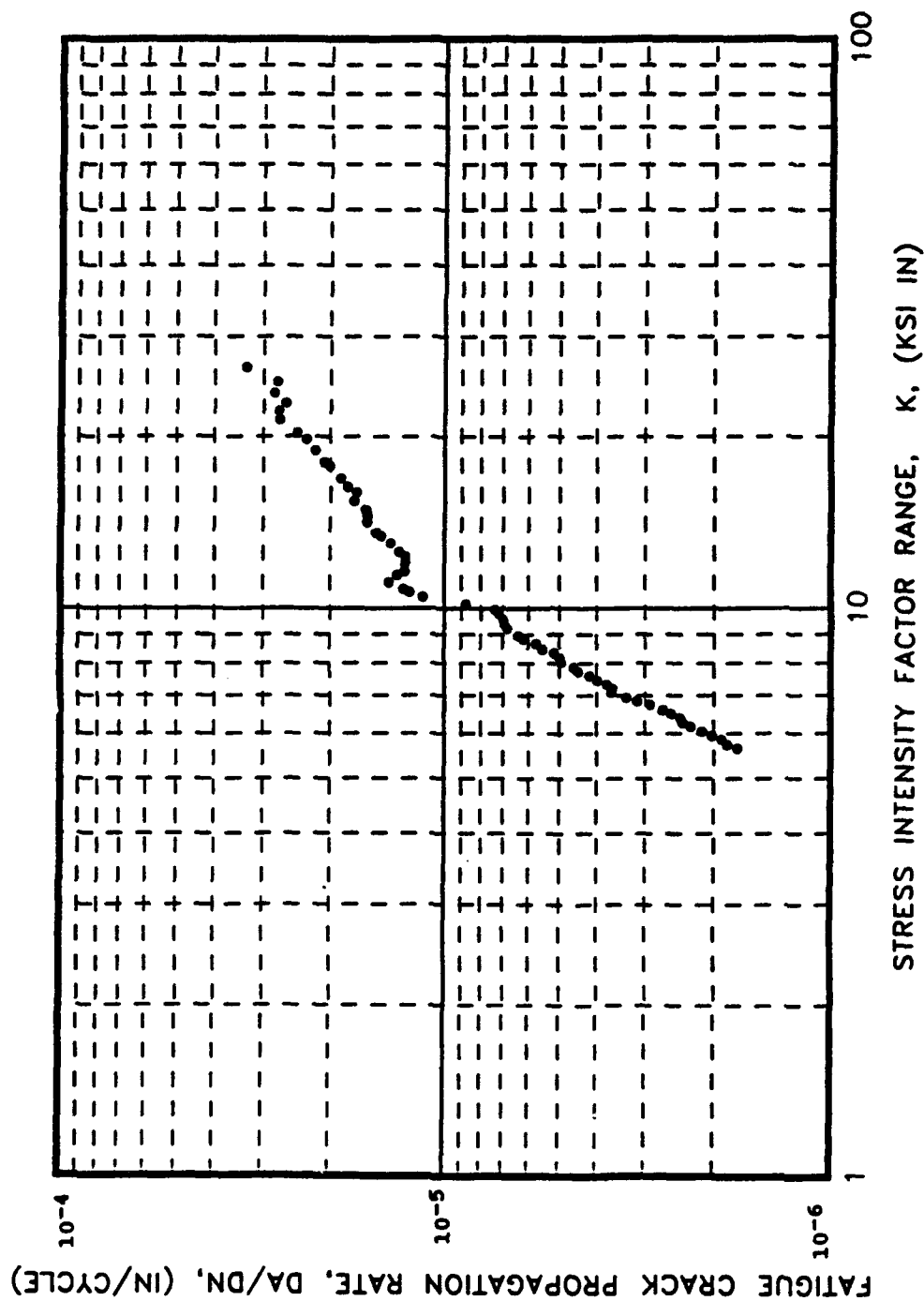


FIGURE R13. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion. (T-L Orientation, Specimen GTL T-3). LTV.

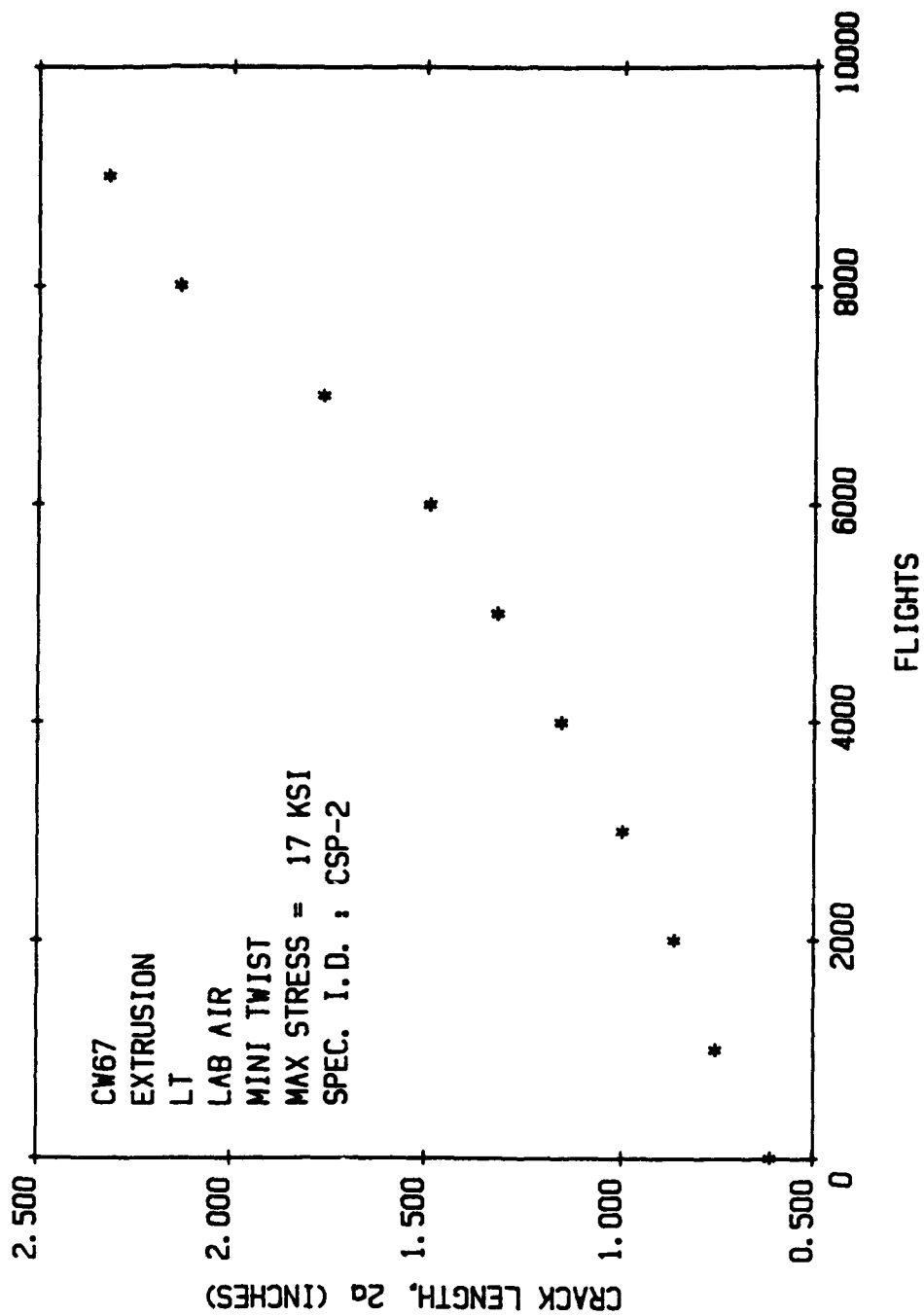


FIGURE R14. Mini-TWIST Spectrum Fatigue Cracklength vs Flights Data for CW67 Extrusion. Air Force.

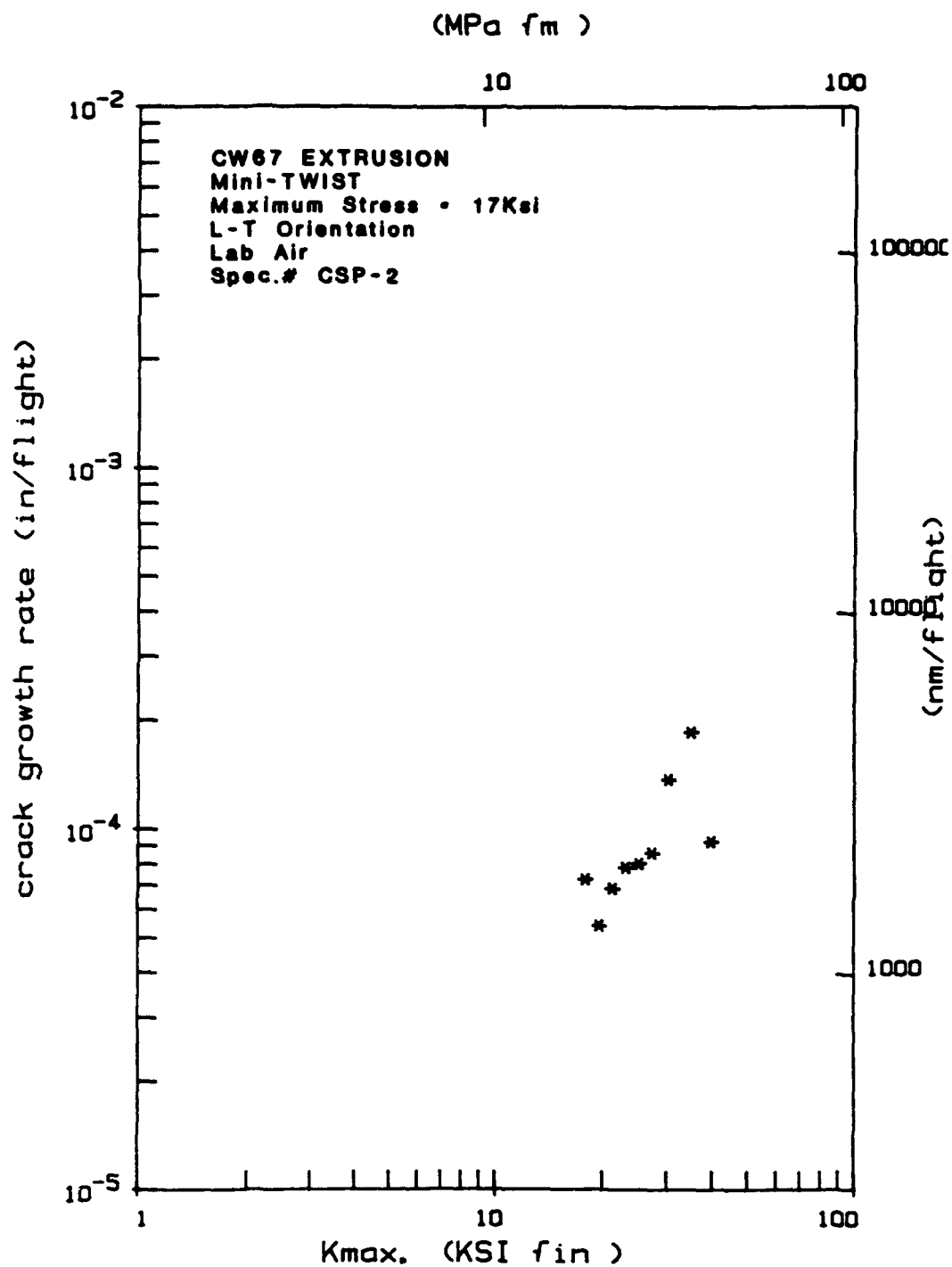


FIGURE R15. Mini-TWIST Spectrum Fatigue Crack Growth Rate Data for CW67 Extrusion. Air Force.

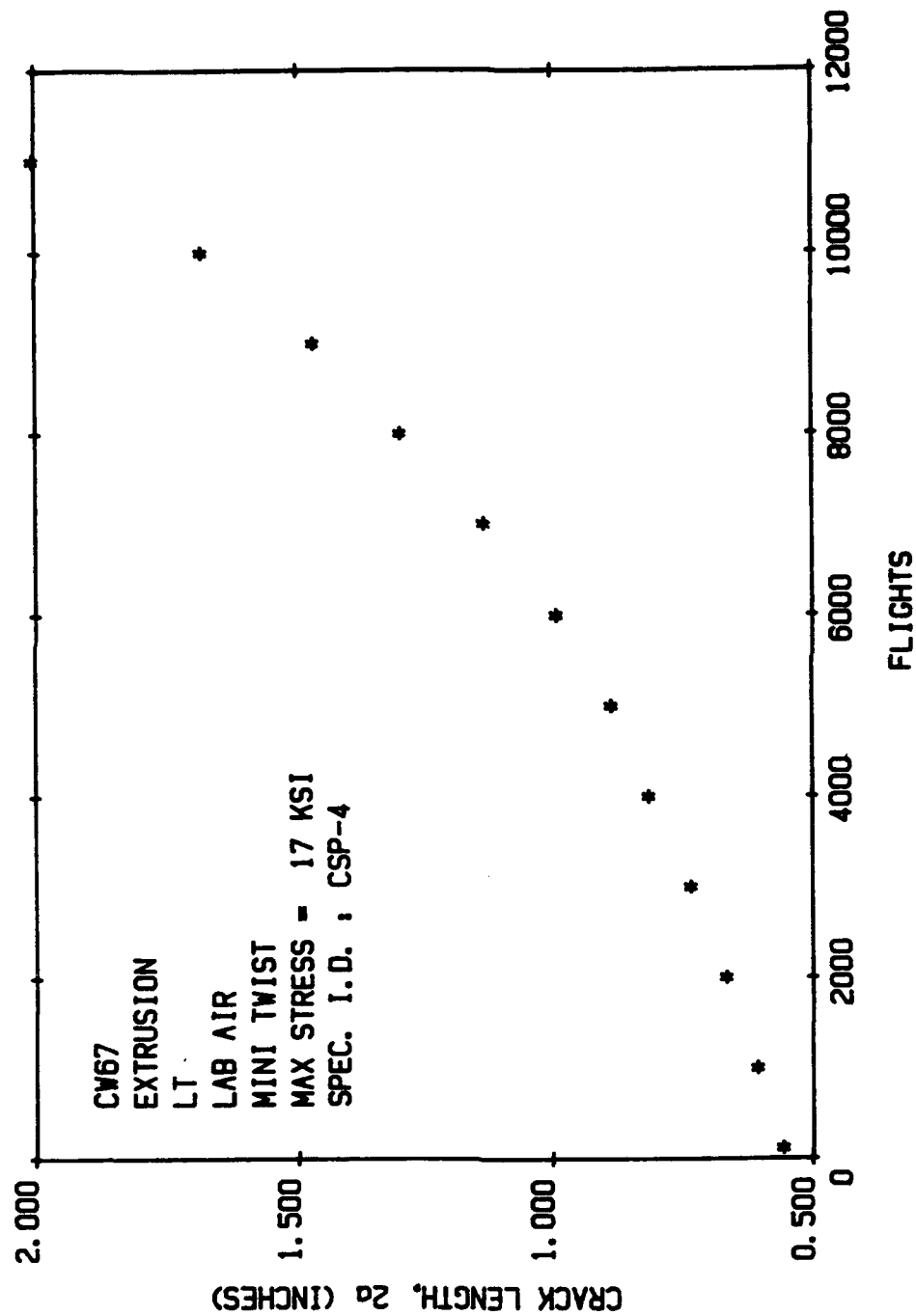


FIGURE R16. Mini-TWIST Spectrum Fatigue Crack Length vs Flights Data for CW67 Extrusion.  
Air Force.

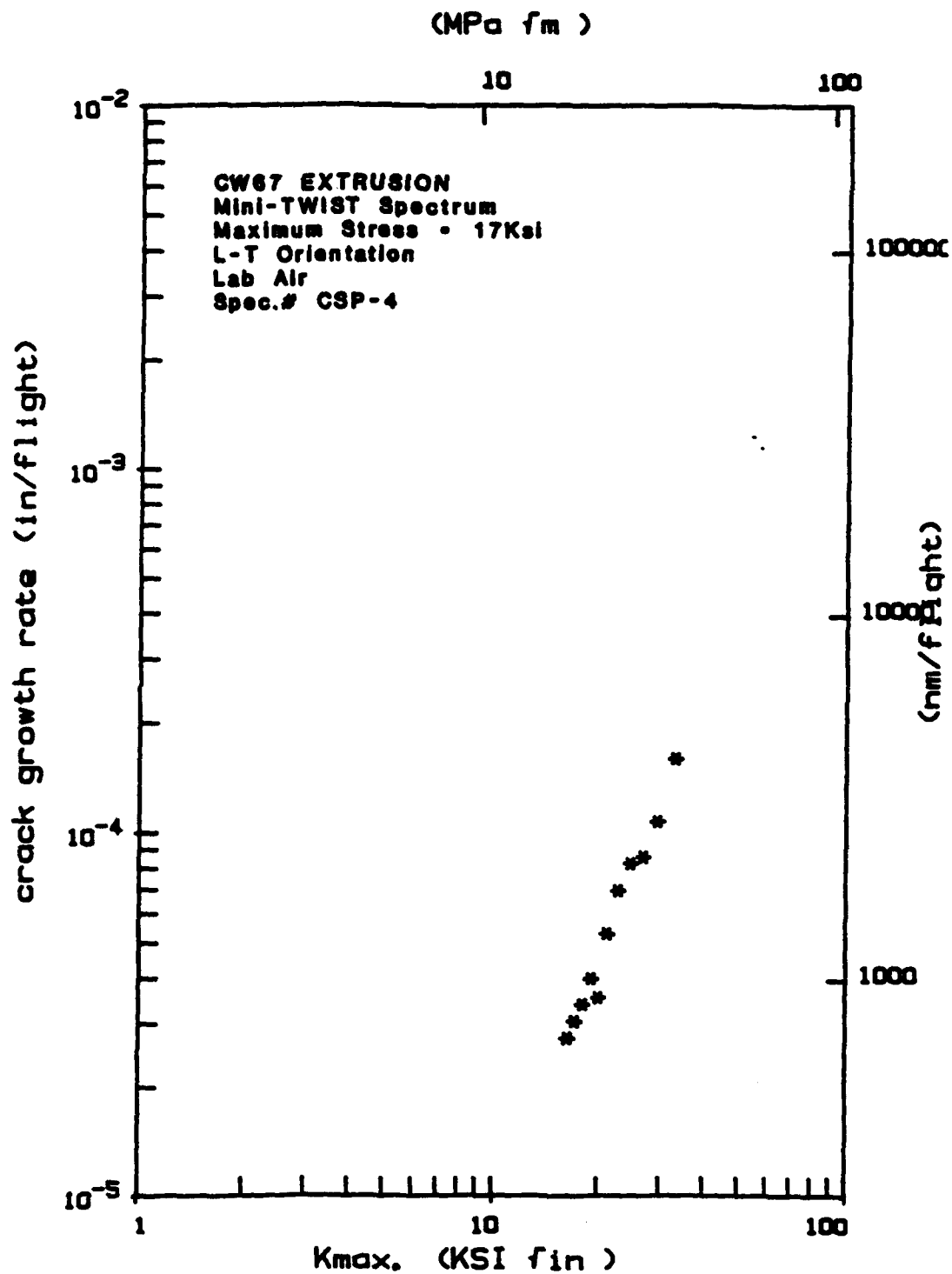


FIGURE R17. Mini-TWIST Spectrum Fatigue Crack Growth Rate Data for CW67 Extrusion.  
Air Force.

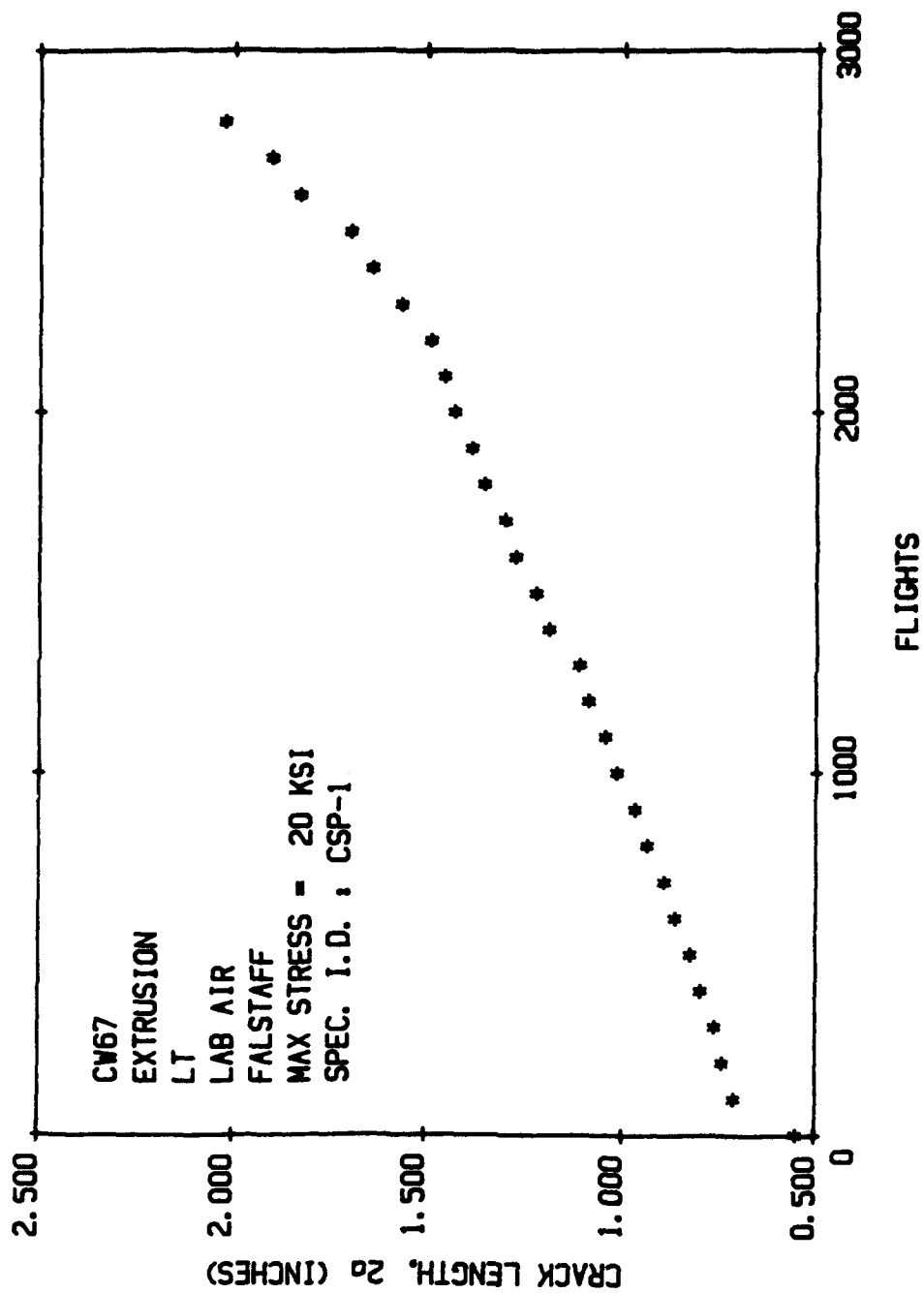


FIGURE R18. FALSTAFF Spectrum Fatigue Crack Length vs Flights.  
Air Force.

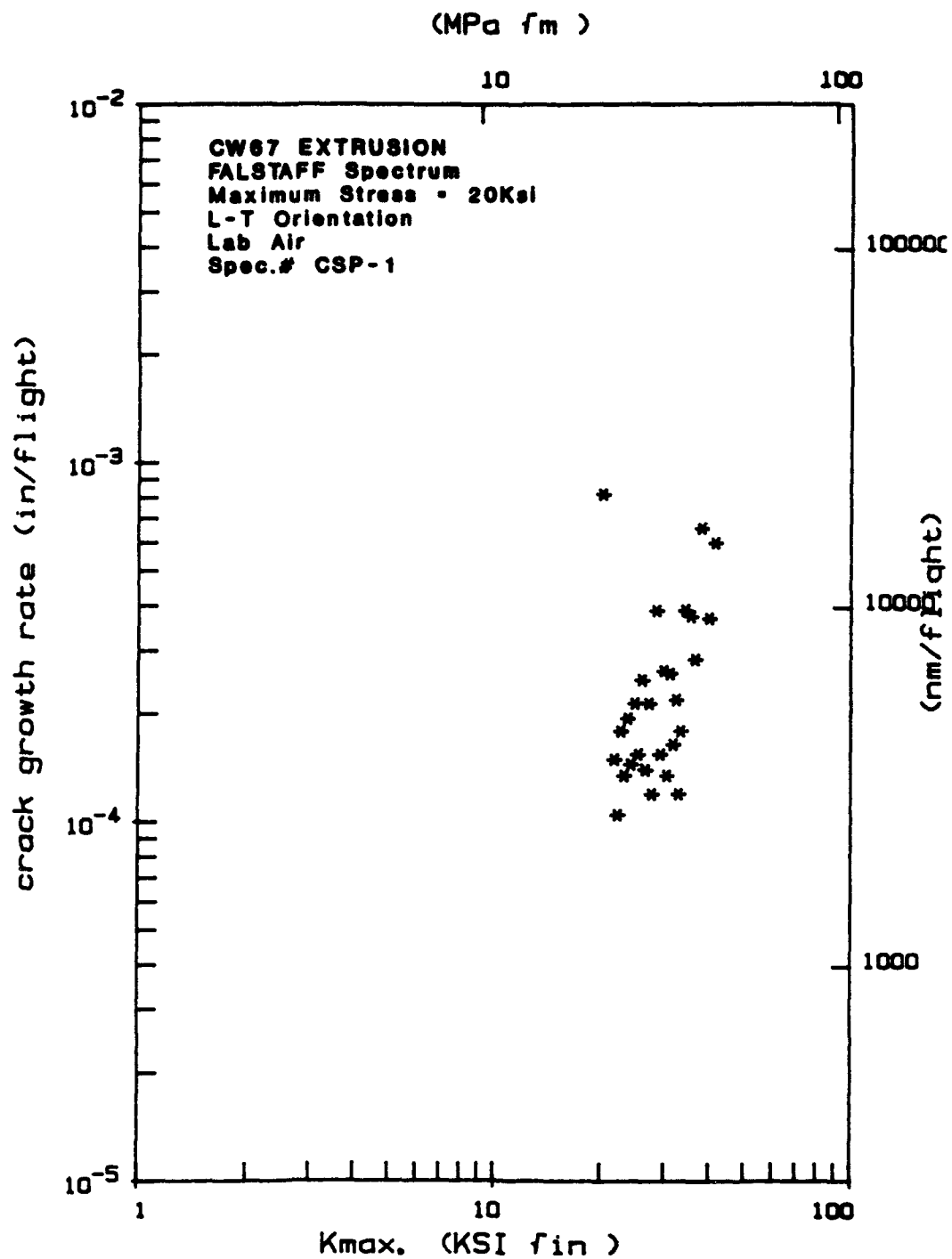


FIGURE R19. FALSTAFF Spectrum Fatigue Crack Growth Rate Data for CW67  
 Extrusion.  
 Air Force.

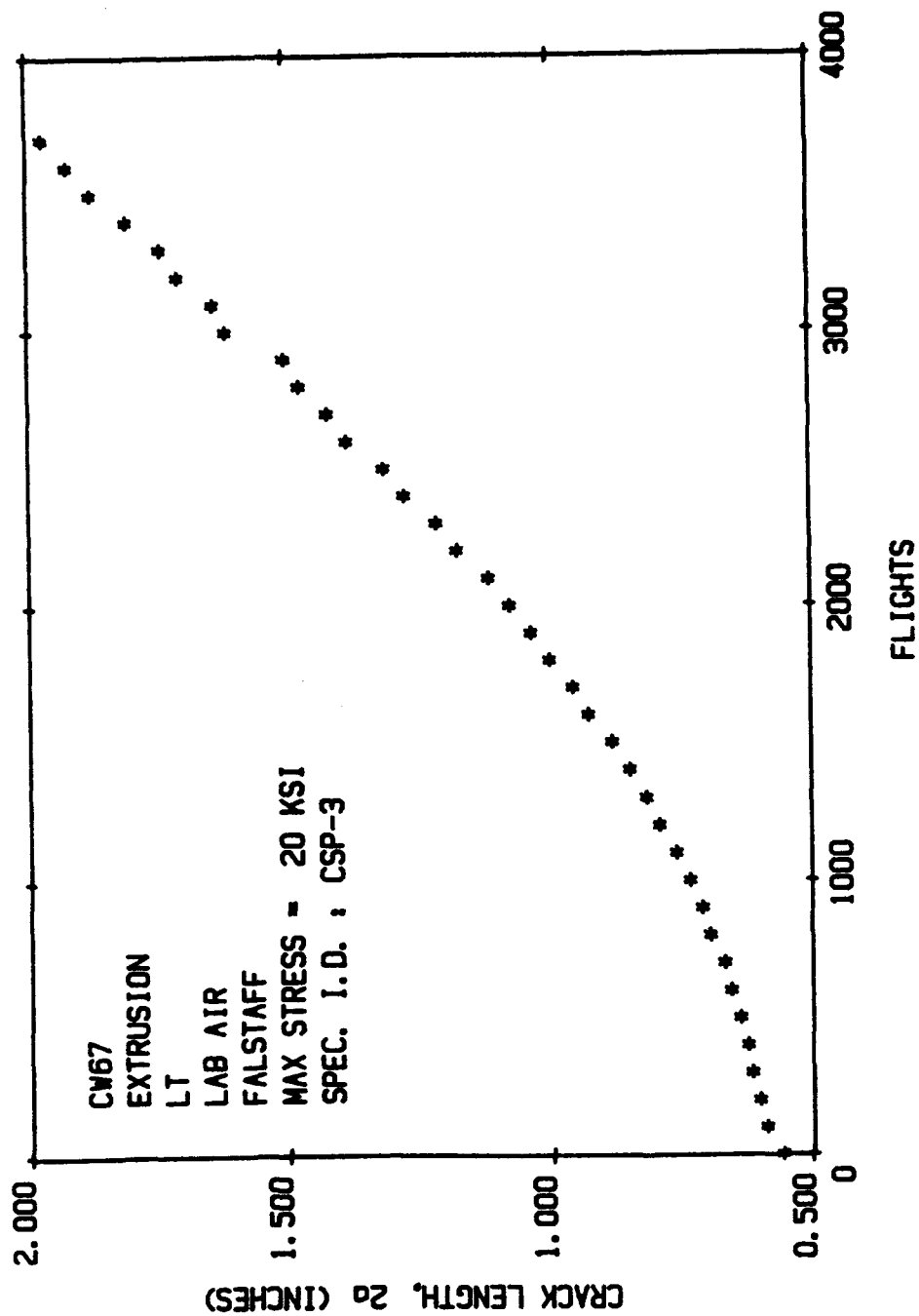


FIGURE R20. FALSTAFF Spectrum Fatigue Crack Length vs Flights.  
Air Force.

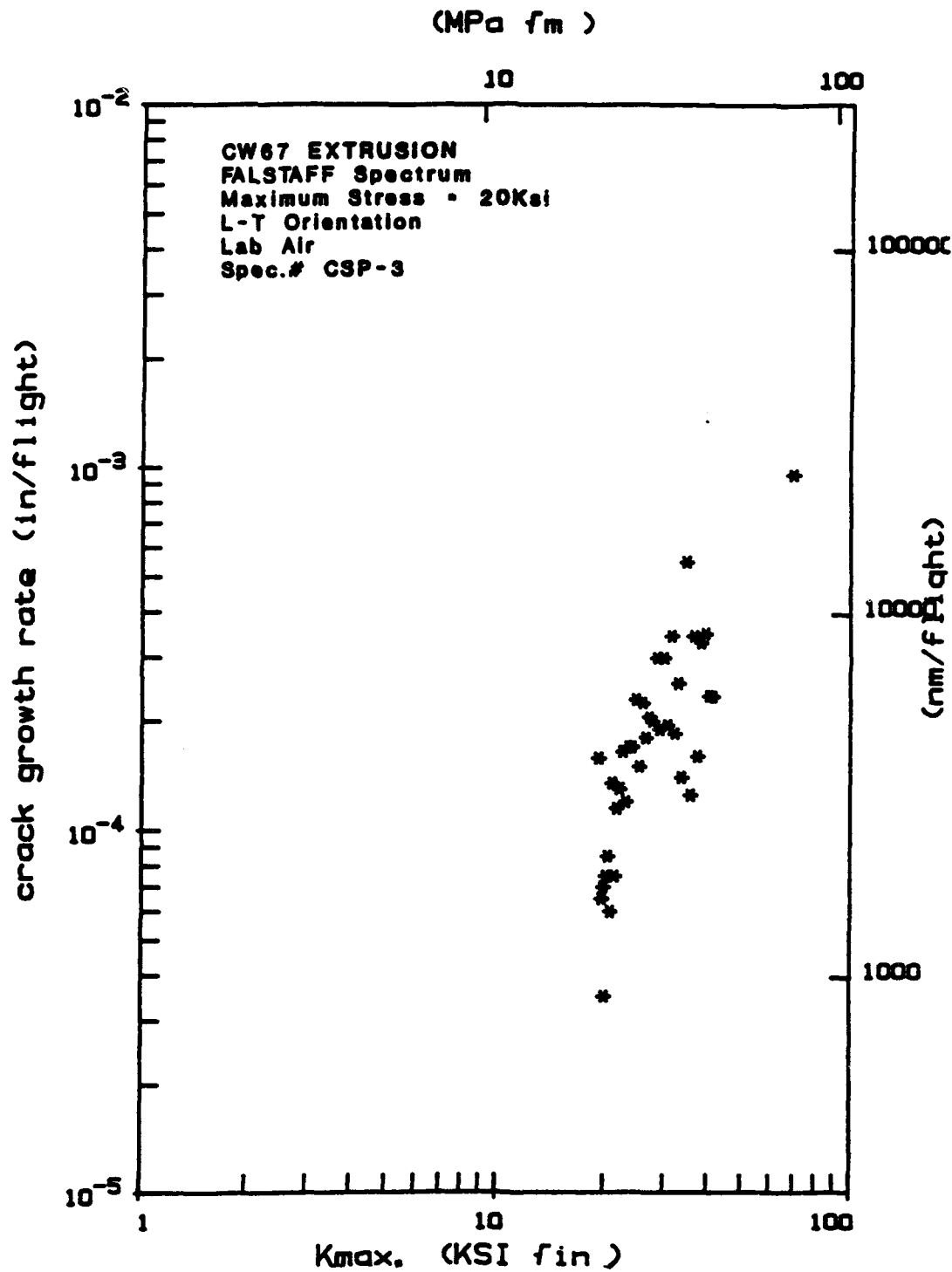


FIGURE R21. FALSTAFF Spectrum Fatigue Crack Growth Rate Data for CW67  
 Extrusion.  
 Air Force.

**APPENDIX S**  
**CW67 HAND FORGING**  
**2.5"X6"X18"**

**INTRODUCTION**

The Alcoa P/M aluminum alloy CW67 2.5"X6"X18" hand forgings were received October 1988. Martin Marietta and the Air Force tested the CW67 forging.

**TESTING**

Mechanical properties (tension, compression, shear, bearing and fracture toughness), and constant amplitude fatigue crack growth tests were generated according to ASTM standards, unless otherwise specified.

Spectrum fatigue crack growth rate tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

TABLE S1  
TENSILE RESULTS FOR  
ALCOA CW67 FORGING

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	RT	LONG	87.2	84.0	13.0	29.6	
MARIETTA,			83.1	75.9	15.0	39.7	
LOUISIANA			85.0	82.5	14.0	27.6	
AIR FORCE	RT	LONG	88.0	83.6	13.0	39.7	
			82.2	78.6	13.8	47.9	
			85.4	80.7	12.7	34.5	
			84.6	80.1	12.1	46.9	
		AVERAGE	85.1	80.8	13.4	38.0	
		STANDARD DEVIATION	2.1	2.9	1.0	7.9	

TABLE S2  
TENSILE RESULTS FOR  
ALCOA CW67 FORGING

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	RT	L TRANS	79.1	73.4	12.0	17.6	
MARIETTA,			78.8	73.0	14.0	25.5	
LOUISIANA			79.4	74.0	17.0	42.5	
AIR FORCE	RT	L TRANS	82.4	77.2	13.9	40.1	
			83.0	77.0	10.2	25.3	
			83.2	77.2	13.5	38.9	
			82.3	75.4	13.0	32.6	
		AVERAGE	81.2	75.3	13.4	31.8	
		STANDARD DEVIATION	2.0	1.9	2.1	9.3	

**TABLE S3**  
**TENSILE RESULTS FOR**  
**ALCOA CW67 FORGING**

COMPANY	TEST TEMP (DEGREES F)	ORIENT- ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	RT	S TRANS	78.7	72.4	12.0	32.7	
MARIETTA, LOUISIANA			77.9	71.5	11.0	32.7	
			77.5	70.8	14.0	36.0	
AIR FORCE	RT	S TRANS	85.7	79.3	6.8	18.1	
			43.8	43.8	9.1	23.1	
		AVERAGE	72.7	67.6	10.6	28.5	
		STANDARD DEVIATION	16.5	13.7	2.7	7.6	

**TABLE S4**  
**COMPRESSION RESULTS FOR**  
**ALCOA CW67 FORGING**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MARTIN	RT	LONG	82.9	10.6
MARIETTA,			81.9	10.6
LOUISIANA			81.4	10.6
AIR FORCE	RT	LONG	81.0	
			79.4	
			77.3	
			76.4	
		AVERAGE	80.0	10.6
		STANDARD DEVIATION	2.4	0.0

**TABLE S5**  
**COMPRESSION RESULTS FOR**  
**ALCOA CW67 FORGING**

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MARTIN	RT	L TRANS	78.6	10.8
MARIETTA,			78.8	11.0
LOUISIANA			79.6	11.0
AIR FORCE	RT	L TRANS	81.6	
			82.5	
			81.5	
			80.0	
		AVERAGE	80.4	10.9
		STANDARD DEVIATION	1.5	0.1

TABLE S6  
COMPRESSION RESULTS FOR  
ALCOA CW67 FORGING

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MARTIN	RT	S TRANS	80.1	10.7
MARIETTA,			82.1	10.8
LOUISIANA			80.2	10.8
		AVERAGE	80.8	10.8
		STANDARD DEVIATION	1.1	0.1

TABLE S7  
PIN SHEAR RESULTS FOR  
ALCOA CW67 FORGING

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
AIR FORCE	LONG	50.0
		50.1
		50.2
		49.8
	AVERAGE	50.0
	STANDARD DEVIATION	0.2

TABLE S8  
PIN SHEAR RESULTS FOR  
ALCOA CW67 FORGING

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
AIR FORCE	L TRANS	49.2
		49.8
		49.5
		49.7
	AVERAGE	49.5
	STANDARD DEVIATION	0.3

**TABLE S9**  
**BEARING RESULTS FOR**  
**ALCOA CW67 FORGING**

COMPANY	ORIENTATION	e/D	BEARING ULT. STRENGTH (KSI)	BEARING YIELD STRENGTH (KSI)
AIR FORCE	LONG	1.5	137.9	122.3
			137.3	118.8
			131.2	118.9
	AVERAGE		135.5	120.0
	STANDARD DEVIATION		3.7	2.0
	L TRANS	1.5	136.0	123.0
			137.4	130.5
			132.4	128.2
	AVERAGE		135.2	127.2
	STANDARD DEVIATION		2.6	3.8
	LONG	2.0	165.5	118.0
			164.9	77.8
			162.7	104.1
	AVERAGE		164.3	100.0
STANDARD DEVIATION		1.5	20.5	
L TRANS	2.0	166.4	103.1	
		168.1	117.5	
		162.1	99.9	
AVERAGE		165.5	106.8	
STANDARD DEVIATION		3.1	9.4	

**TABLE S10**  
**FRACTURE TOUGHNESS RESULTS FOR**  
**ALCOA CW67 FORGING**

COMPANY	ORIENTATION	K <sub>IC</sub> (KSI in <sup>0.5</sup> )	K <sub>q</sub> (KSI in <sup>0.5</sup> )	COMMENT
MARTIN MARIETTA, LOUISIANA	L - T	44.8	35.9	VALID INVALID(1)
AIR FORCE	L - T		28.8 34.4	INVALID(2) INVALID(2)
	AVERAGE	44.8	33.0	
	STANDARD DEVIATION	0.0	3.8	

(1): a/W > 0.55

(2): EXCESSIVE CRACK FRONT CURVATURE

**TABLE S11**  
**FRACTURE TOUGHNESS RESULTS FOR**  
**ALCOA CW67 FORGING**

COMPANY	ORIENTATION	K <sub>IC</sub> (KSI in <sup>0.5</sup> )	K <sub>q</sub> (KSI in <sup>0.5</sup> )	COMMENT
MARTIN MARIETTA, LOUISIANA	L - S		46.7 52.5	INVALID(1) INVALID(1)
		38.6		VALID
	AVERAGE	38.6	49.6	
	STANDARD DEVIATION	0.0	4.1	

(1): a/W > 0.55

TABLE S12  
FRACTURE TOUGHNESS RESULTS FOR  
ALCOA CW67 FORGING

COMPANY	ORIENTATION	KIC (KSI in <sup>0.5</sup> )	Kq (KSI in <sup>0.5</sup> )	COMMENT
MARTIN MARIETTA, LOUISIANA	T - L	25.0		VALID
		21.6		VALID
AIR FORCE	T - L		21.0	INVALID(1)
			18.6	INVALID(1)
			22.5	INVALID(1)
	AVERAGE	23.3	20.7	
	STANDARD DEVIATION	2.4	2.0	

(1): EXCESSIVE CRACK FRONT CURVATURE

TABLE S13  
FRACTURE TOUGHNESS RESULTS FOR  
ALCOA CW67 FORGING

COMPANY	ORIENTATION	KIC (KSI in <sup>0.5</sup> )	Kq (KSI in <sup>0.5</sup> )	COMMENT
MARTIN MARIETTA, LOUISIANA	T - S	21.3		VALID
			23.5	INVALID(1)
	AVERAGE	21.3	23.5	
	STANDARD DEVIATION	0.0	0.0	

(1):  $a/W > 0.55$

**TABLE S14**  
**FRACTURE TOUGHNESS RESULTS FOR**  
**ALCOA CW67 FORGING**

COMPANY	ORIENTATION	K <sub>IC</sub>	K <sub>q</sub>	COMMENT
		(KSI in <sup>-0.5</sup> )	(KSI in <sup>-0.5</sup> )	
-----				
AIR FORCE	S - T		20.9	INVALID(1)
			25.3	INVALID(1)
			23.6	INVALID(1)
	AVERAGE		23.3	
	STANDARD DEVIATION		2.2	
(1): EXCESSIVE CRACK FRONT CURVATURE				

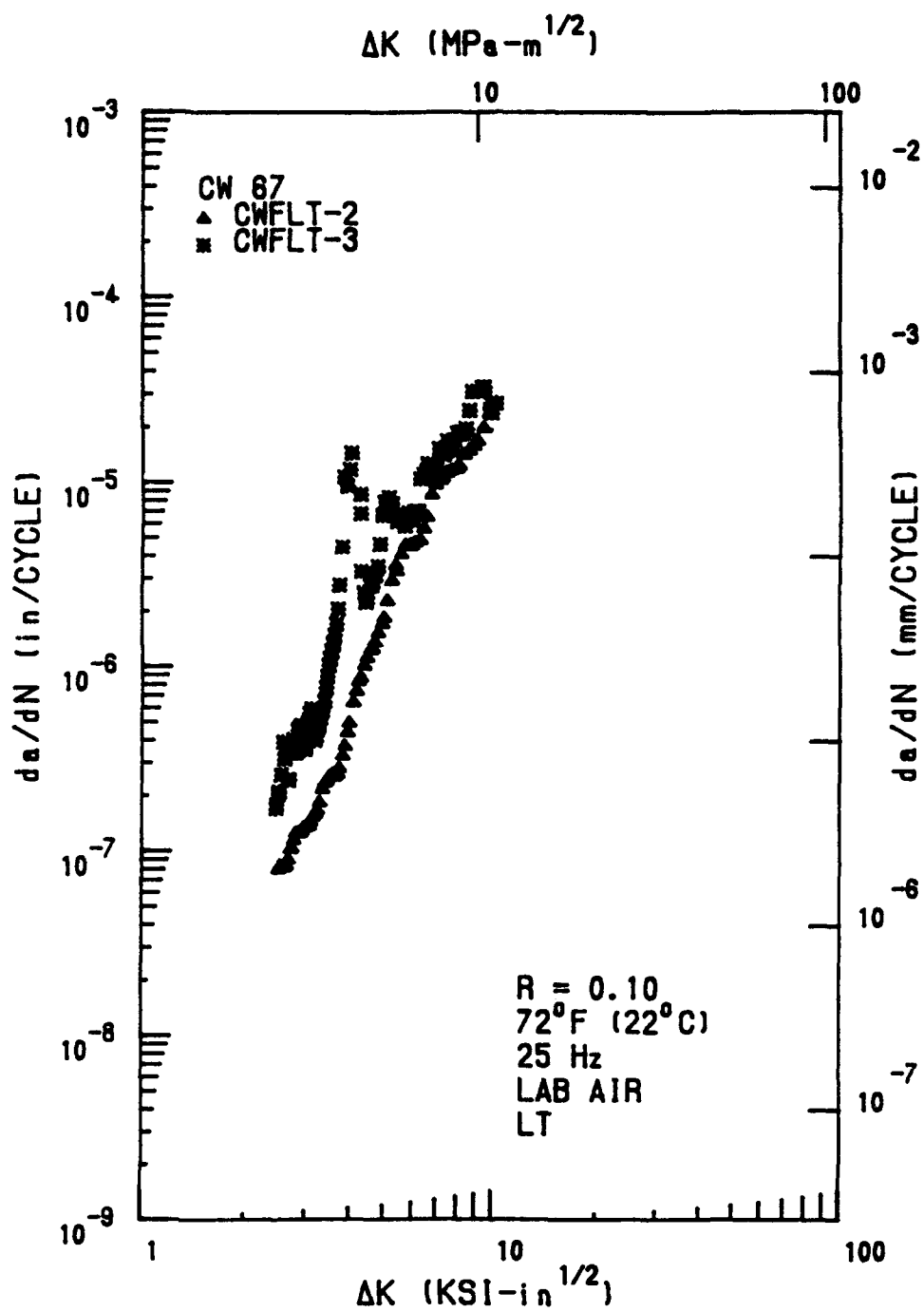


FIGURE S1. Fatigue Crack Growth Rate Data for CW67 Forging (L-T Orientation). Air Force.

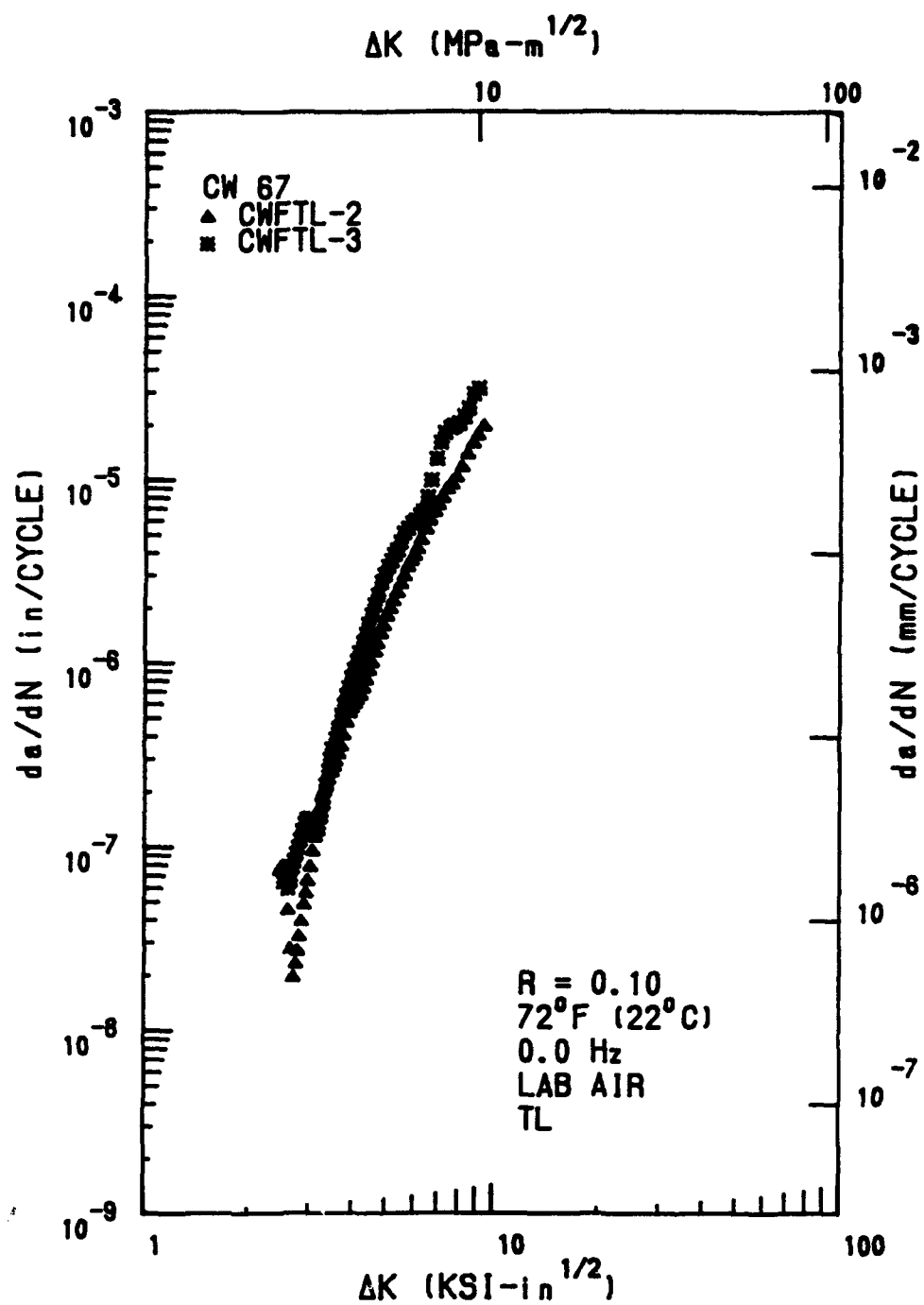


FIGURE S2. Fatigue Crack Growth Rate Data for CW67 Forging (T-L Orientation). Air Force.

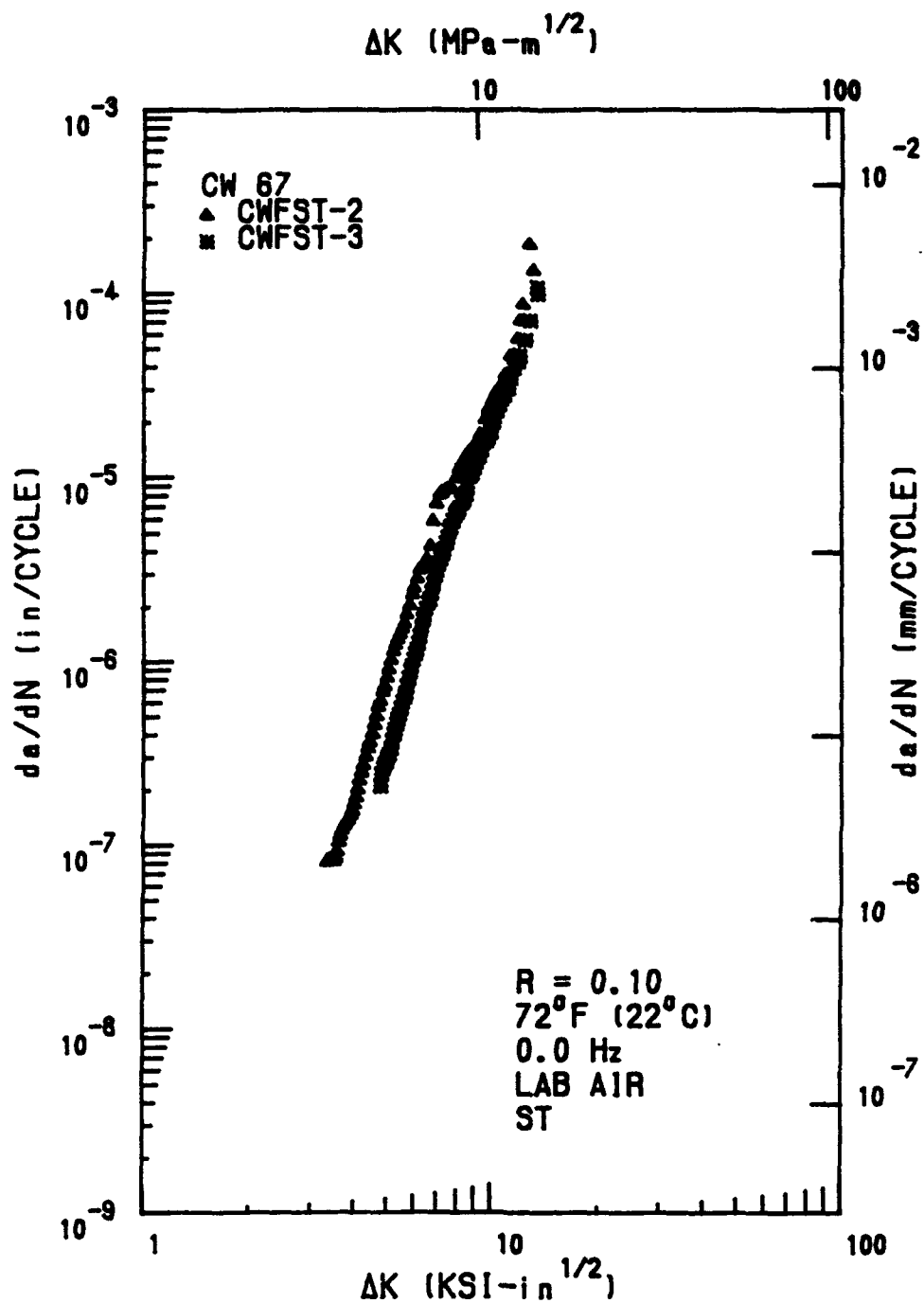


FIGURE S3. Fatigue Crack Growth Rate Data for CW67 Forging (S-T Orientation). Air Force.

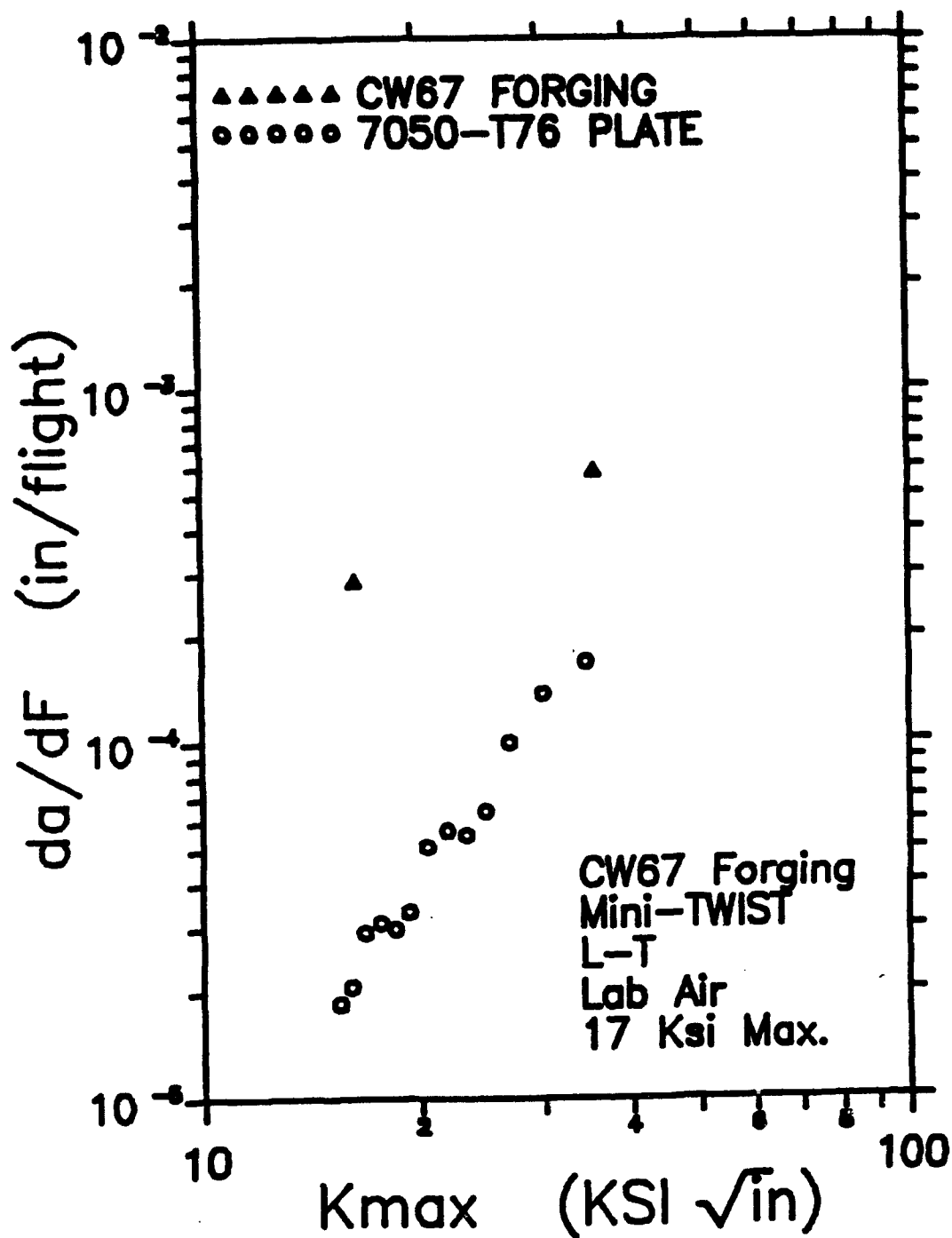


FIGURE S4. Comparison of CW67 Forging and 7050 Plate Mini-TWIST Spectrum  
 Fatigue Crack Growth Rate Data (L-T Orientation).  
 Air Force.

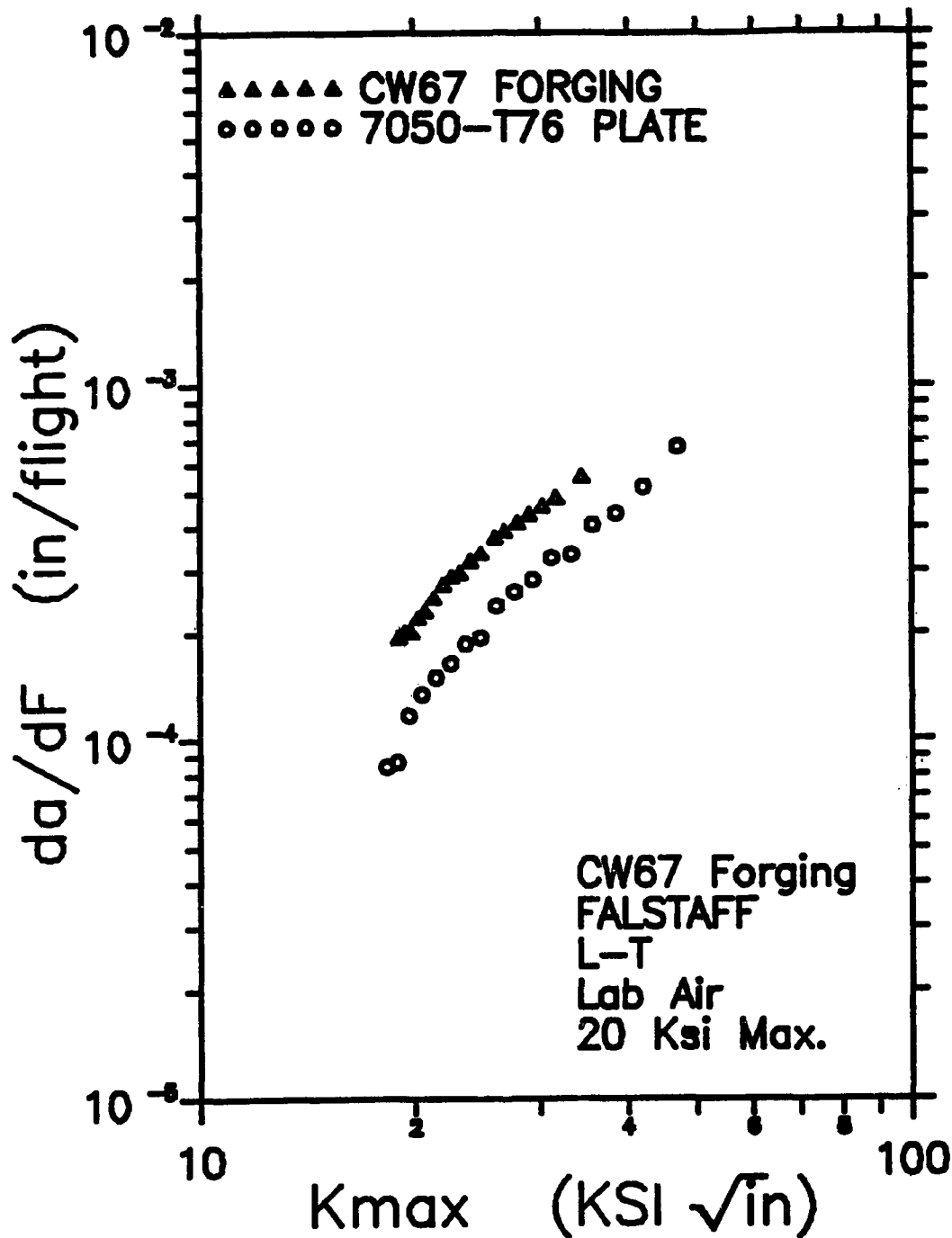


FIGURE S5. Comparison of CW67 Forging and 7050 Plate FALSTAFF Spectrum Fatigue Crack Growth Rate Data (L-T Orientation). Air Force.